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INTRODUCTION TO SYMPOSIUM ON PROBLEMS OF MISSISSIPPIAN STRATIGRAPHY AND CORRELATION

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One of the most important results of the work of the Mississippian subcommittee of the National Research Council's Committee on Stratigraphy has been the bringing to light of numerous large problems of stratigraphy and correlation of the Mississippian formations of North America. All these problems have been known to some Mississippian stratigraphers, but few of them have been widely recognized. The existence of some (for example, our sadly deficient knowledge of the Mississippian rocks of the Appalachian region) has probably been unsuspected by most geologists.

The papers of the symposium presented here were solicited by me from among those stratigraphers and paleontologists who seemed best qualified to discuss some of these problems. Selection of problems was necessary in order to hold the symposium within reasonable bounds. In order that the symposium might be of broad interest, the subjects were purposely chosen to encompass a wide geographic range and to include also problems in surface stratigraphy, subsurface correlation, paleogeography, classification, and paleontology. This range of subjects is not exhaustive, however, and numerous other problems of equal, or nearly equal, importance are not touched upon.

The papers of this symposium (except that by Stoyanow) were read before Section E of the American Association for the Advancement of Science in Chicago on December 26, 1947. All are presented here except that by Miller, who feels that further studies are needed before any significant addition can be made to his contribution (in Weller *et al.*, 1948) to the text accompanying the Mississippian Correlation Chart.

The papers of this symposium can be classified roughly in three groups as follows:

1. Those which are concerned principally with important gaps in knowledge and which suggest investigations that are urgently needed. Included in this group are the papers by Byron Cooper, Stockdale, and Williams.

2. Those which are concerned principally with the compilation of data, inadequately presented elsewhere, relevant to certain problems, to which is added more or less new information. Some of

the conclusions reached must be recognized as controversial. These include the papers by Swann and Atherton, Reed, Stoyanow, Miller, Chalmer Cooper, Arnold, and Moore.

3. Those which are more frankly controversial and present viewpoints and conclusions not adequately set forth in other recent publications but not subscribed to by all qualified geologists. These include the papers by Laudon and Selk.

If these papers serve to focus attention on some of the principal problems of Mississippian stratigraphy and correlation in North America and result in the renewal or expansion of investigations designed to solve them, this symposium may be considered to have been successful.

REFERENCE CITED

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STATUS OF MISSISSIPPIAN STRATIGRAPHY IN THE CENTRAL AND NORTHERN APPALACHIAN REGION[1]

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ABSTRACT

Critical study of published information on the Mississippian system of the Appalachian region reveals long and continuing neglect of some of the thickest and most varied sections of the Mississippian in North America.

Abundant faunas and floras in the Appalachian Mississippian have received surprisingly little systematic study and description. These assemblages offer exceptional opportunities for paleontological and biostratigraphical study. Only a beginning has been made toward understanding the local and regional relationships of numerous facies. In many sections of the Appalachian region, the determination of the position, stratigraphic character, and geologic significance of both systemic boundaries awaits detailed study. A large number of correlations and formation identifications, now current, are not only valueless but deceiving because they are based upon inadequate paleontology or in some instances upon no paleontology. The widespread persistence of certain lithologic types has been mistaken for evidence of contemporaneous deposition, with lamentable results.

The keynote of this summary is a strong and urgent plea for renewed interest in Appalachian stratigraphy and for an early beginning to the systematic study of Mississippian fossils.

INTRODUCTION

The stratigraphic classifications of the Mississippian system in the central and northern Appalachian region embrace three generations of stratigraphic names. "Pocono" and "Mauch Chunk" were introduced by Lesley (1876) as substitutes for the Rogers brothers' "Vespertine" (1844) and "Umbral" (1858), which were the original names applied to the lower and upper parts of the thick Mississippian clastics of northeastern Pennsylvania. W. B. Rogers (MacFarlane, 1879, p. 179) used "Greenbrier limestone" for the limestone below the Mauch Chunk and above the Pocono formation.

The second generation of stratigraphic names, including "Chattanooga," "Grainger," "Fort Payne," "Hinton," "Bangor," "Floyd," "Bluefield," "Princeton," "Bluestone," "Newman," and "Loyalhanna," were introduced during the 1890's and early 1900's, when so many of the classic folios of the United States Geological Survey were prepared. These names were applied to gross lithologic divisions which served as the mapping units of that period.

Third-generation stratigraphic names arose largely from the work of Charles Butts and David B. Reger. Following monographic studies of the Mississippian of Kentucky, Butts (1917, 1922) used Mississippi Valley and Ohio Valley names for some of the divisions of the Appalachian Mississippian. His recognition of the correlatives of the type Mississippian formations was based upon the presence of certain fossils which had been found to be useful guides in the thinner sections prevailing in the Mississippi Valley. In classifying the Mississippian beds from Pennsylvania to Alabama, Butts (1926, 1927, 1932, 1933, 1940) used the names "Warsaw," "St. Louis," "Ste. Genevieve," "Gasper," "Golconda," "Cypress," and "Glen Dean" in a time-stratigraphic sense.

Reger (1926) introduced a long list of stratigraphic names for minor subdivisions of the Mississippian of West Virginia. The names were proposed on the basis of detailed measurement and description of a few stratigraphic sections,

[1] Manuscript received February 18, 1948.

but none of the newly named units was mapped separately. Some of his units in the Greenbrier and Mauch Chunk series have been used in other parts of West Virginia and in some parts of Virginia (fig. 1), but most of the divisions which he recognized have not been traced very far from the sections where they were originally described. No systematic work has been published on the faunas of these units.

Reger (1926) also used some Ohio Valley names for parts of the Appalachian Mississippian, but the names were not used with the support of stratigraphic or paleontological evidence. His recognition of a "Sunbury shale" and "Berea sandstone" is particularly objectionable because their use implies correlations of the most precise character, which are actually based on equivocal evidence. The use of these and other stratigraphic names from the Central Interior region of the United States has misled many geologists into believing that the Mississippian system of the Appalachian region is rather fully understood.

Actually, the stratigraphic nomenclature for the Mississippian of the Appalachian province is most unsatisfactory and is almost wholly inadequate as a framework for understanding the complex variations of the succession. Some elements of the classification are based upon the persistence of certain lithologies whose lower and upper limits are regarded as reliable time boundaries. Facies relationships have been largely ignored. The stratigraphic work upon which the succession was divided into formations was almost entirely of a physical character, and it has been carried on in a near-vacuum of systematic paleontology. Thus many regional correlations are inaccurate.

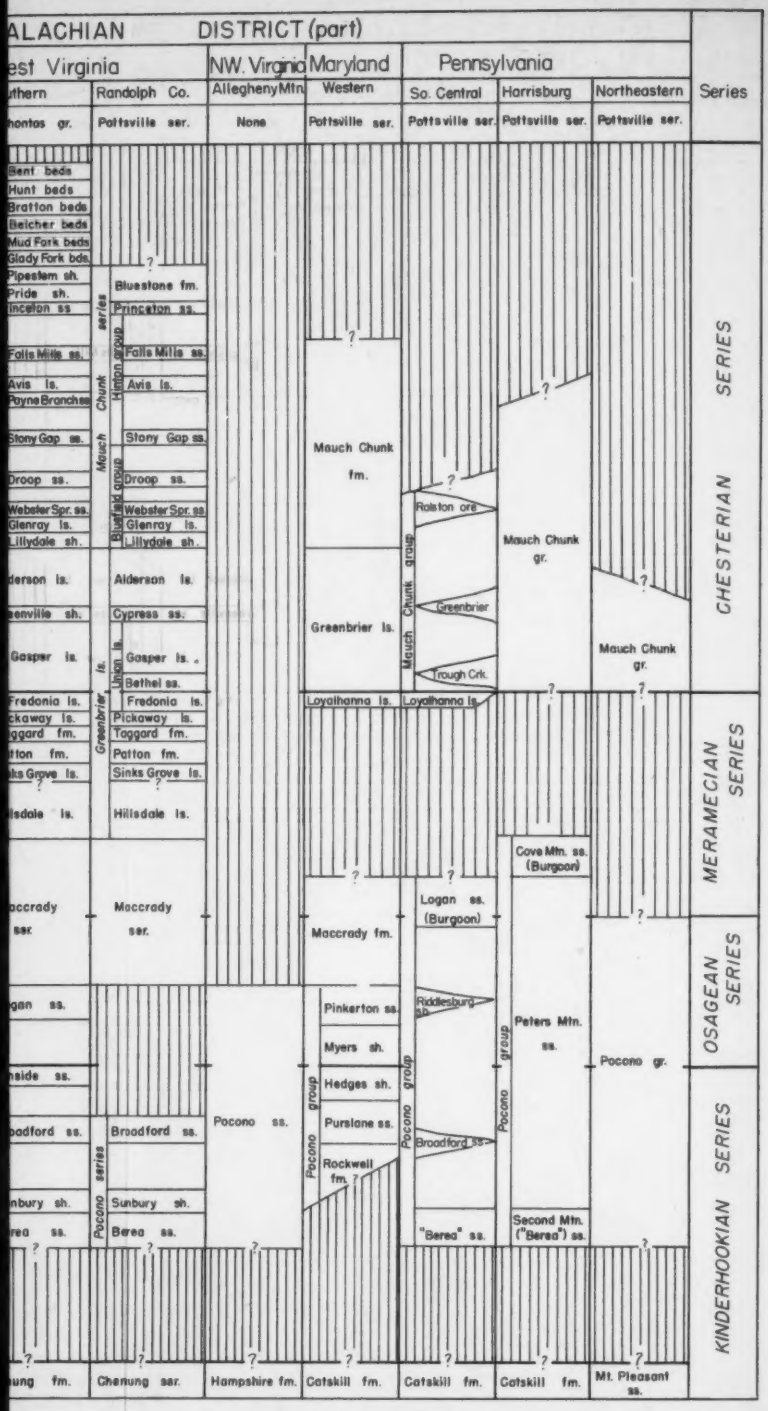
In order to make rough differentiations of many formations, stratigraphers found it necessary to place heavy reliance upon a few so-called "guide fossils," on the basis of observed ranges in the type Mississippian. The trivial character of some of the paleontological data used in delimiting certain Appalachian formations is exemplified by the determination of 1,500 feet of limestone in the thick Mississippian of Washington County, Virginia, as "Ste. Genevieve limestone" on the basis of the observed range of the columnal plates of *Platycrinites huntsvillae* (Butts, 1940, pp. 369–371).

GENERAL ASPECTS OF THE MISSISSIPPIAN SYSTEM

In Pennsylvania the Mississippian consists mainly of clastic strata with a total maximum thickness of about 4,000 feet. The lower division, the Pocono sandstone, is well over 1,000 feet thick and is composed primarily of arkosic cross-bedded conglomeratic beds which locally contain plant fossils. The thick Pocono is overlain in northeastern Pennsylvania by the Mauch Chunk red beds. In southwestern Pennsylvania, the Loyalhanna sandy limestone intervenes between the Mauch Chunk red beds and the Pocono. Butts (1924) regarded the Loyalhanna as the much thinned extension of the Ste. Genevieve limestone. The upper Mississippian boundary, as marked by the contact between the Mauch Chunk red beds and the thick, ledge-making Pottsville sandstone and conglomerate, is very sharp. Likewise, the conglomeratic beds in the lower part of the Pocono are rather easily differentiated from the red beds of the Catskill facies.

The generally coarse and nonmarine character of the Pocono of Pennsylvania prevails without much change south-

FIG. 1.—Mississippian formations in the central and northern Appalachian region (based upon correl
Research Council Mississippian Subcommittee).



ed upon correlation chart of Mississippian formations of North America, by the National

ward to the latitude of the James River, beyond which the cross-bedded arkosic Pocono strata with plant fossils are gradually supplanted by thin, rusty-weathering sandstones and shales with marine fossils. One thin tongue of Pocono lithology extends as far south as Moccasin Gap, Scott County, Virginia, within a few miles of the Tennessee state line. The rusty-weathering marine beds were named the "Grainger shale" by Keith (1896), but since 1925 the name "Price sandstone" (Campbell, 1925) has been generally used instead of Grainger. Farther southwest toward Cumberland Gap, the Price or Grainger and the underlying Devonian beds with similar lithology are supplanted by a great body of Chattanooga black shale (Hayes, 1891).

The Greenbrier limestones which are so prominently exposed in Virginia and West Virginia are exceedingly thin in Pennsylvania, but in central-western Virginia in the Greendale syncline the Mississippian limestones are more than 4,000 feet thick. Toward Cumberland Gap the Greenbrier limestones become much reduced in thickness and are known as the "Newman limestone" (Campbell, 1893). Part of the Newman is younger than the Greenbrier (fig. 1; Butts, 1940, pp. 405–406).

The Mauch Chunk red beds persist southwestward into West Virginia and Virginia but become variegated and considerably more fossiliferous than they are in Pennsylvania. In the Bluefield area of Virginia–West Virginia, the thick upper part of the Mississippian is composed of ledge- and ridge-making sandstones, red and green variegated fossiliferous shales, thin coal zones with plant fossils, and thin limy members. The lower 1,000–1,800 feet of the succession is the Hinton group of West Virginia (fig. 1) and the Pennington formation of Virginia. The topmost Mississippian formation consists of about 850 feet of beds very similar to the Pennington or Hinton but separated from these lower divisions by a thin persistent conglomeratic sandstone known as the "Princeton formation" (Campbell, 1896). Southward from Bluefield, the Pennington-Princeton-Bluestone succession thins to 150 feet of sandstone at Cumberland Gap. Below this sandstone at Cumberland Gap is a thick limestone, identified by Butts as equivalent to the Glen Dean limestone of the Ohio Valley. The so-called "Glen Dean" at Cumberland Gap is about the same as the Bluefield shale, which underlies the Pennington or Hinton in the Bluefield area.

Figure 1 shows the classification of the Mississippian formations in ten sections between Harrisburg, Pennsylvania, and Cumberland Gap, Virginia-Tennessee-Kentucky. This chart is reproduced almost without change from the Correlation Chart prepared by the Mississippian Subcommittee of the National Research Council (Weller *et al.*, 1948). However, the fossils listed are those particularly relevant to Appalachian stratigraphy. They are not to be considered as absolutely valid guides to the ranges indicated.

The lamentable inadequacy of our knowledge of the Appalachian Mississippian is primarily the result of continuing inactivity in the study of Mississippian faunas of the region. The Mississippian is characterized by facies fully as varied as those prevailing in the Devonian system of New York and in the Appalachian region. The differentiation of the complex facies of the New York Devonian was made possible largely through the accumulation of a wealth of biostratigraphical data from the study of the rich Devonian faunas of that state.

Facies studies of the Appalachian Mississippian have been slowed because of the dearth of systematic work on the fossils.

A comprehensive survey of the stratigraphic problems of the Appalachian Mississippian is beyond the scope of this summary, the primary purpose of which is to stimulate greater interest in the succession than has prevailed during the past. Three fundamental aspects of Mississippian stratigraphy will be discussed in the light of the problems needing special attention.

SYSTEMIC BOUNDARIES

In central-western Virginia and in adjoining counties of West Virginia the positions of the upper and lower boundaries of the Mississippian system are obscured. In this particular area the position of the systemic boundaries is of great importance because the system therein probably is the fullest Mississippian section on the North American continent.

The lower boundary is within a thick succession of rusty-weathering marine sandstones and shales, the lower part of which is Devonian and the upper part Mississippian. The lower part of the body of sandstone and shale was called "Kimberling shale" and the upper part the "Grainger shale" in some of the early folios of the United States Geological Survey (Campbell, 1896, 1897). More recently, Butts (1932, 1940) has used "Chemung" for the upper part of the Kimberling shale. Since 1925, "Price sandstone" has been used for the beds formerly called "Grainger shale" (Campbell, 1925).

Inasmuch as Butts (1940, pp. 347–350) considered the entire Price formation to be Osagean, he recognized a major hiatus between the Price and the underlying "Chemung." Actually, the Price-"Chemung" succession is transitional in character, with no obvious differentiation of the beds into Mississippian and Devonian components. Butts preferred to draw the base of the Mississippian at the first appearance of *Spiriferina* and *Syringothyris*, but both these genera of brachiopods are now known from Devonian beds. Furthermore, the supposed Osagean age of all the Price formation can no longer be affirmed. Although it is true that the Keokuk age of the upper part of the Price seems to be reliably indicated by a Keokuk fauna containing *Tetracamera subtrigona*, *Orthotetes keokuk*, and *Syringothyris texta*, the lower parts of the Price which contain fossils of early New Providence and Cuyahoga age are probably Kinderhookian (fig. 1). The three species named have been collected from the upper 100 feet of the Price formation near Bluefield, Virginia–West Virginia (Cooper, 1944, pp. 150–151). Two genera of goniatites have been found in the lower Price, *Protocanites lyoni* (Miller, 1936) and *Munsteroceras* (Cooper, 1939, p. 52), both of which occur in the Kinderhookian Chouteau limestone of the type Mississippian.

Recently the writer studied the Devonian-Mississippian succession along New River north of Parrott Station on the Norfolk and Western Railway, Pulaski County, Virginia. Beneath the coarse quartz-pebble conglomerate (Cloyd) at the base of the Price formation and above the highest beds with *Spirifer disjunctus* is a 350–500-foot succession containing fossils of obviously Kinderhookian aspect. A small, rather narrow *Syringothyris*, with a posteriorly deflected ventral cardinal area, and a spiriferoid of the type of *Cyrtospirifer marionensis* are two members of a varied fauna. It is probable that Reger (1926, pp. 505, 520) was deal-

ing with the same fauna and beds when he named the Broadford sandstone from exposures in Smyth County, Virginia. The presence of Kinderhookian beds in the Price and subjacent beds seems established, but the limits of the series are still unknown.

In southwestern Virginia between Cumberland Gap and Bluefield, the Kimberling-Grainger sandstones and shales merge laterally with a thick body of black shale. Where the latter facies predominates, as in western Scott and Lee counties, Virginia, the faunal evidence for drawing the lower systemic boundary is rather meager and equivocal. Although Joel H. Swartz (1926, 1927) has done much to clarify the age relations of various elements of the Chattanooga shale and the probable position of the Devonian-Mississippian boundary, his conclusions should be tested in other areas of the southern Appalachian region.

The upper Mississippian boundary in central-western Virginia and in Mercer County, West Virginia, is somewhere within a thick development of post-Elvira, pre-Pottsville sandstones and shales. The Chester equivalents are over 3,000 feet thick. Very little is known of the faunas of these high Mississippian beds. Near Bluefield, West Virginia, *Sulcatopinna missouriensis*, *Spirifer increbescens*, and *Composita subquadrata* occur in the upper part of the Pennington formation and about 850 feet below the supposed base of the Pennsylvanian Lee formation. These three species collectively delimit the Menard-Kinkaid interval of the Elvira group in the Mississippi Valley. In view of the limited range of these species, the affinities of the faunas occurring in the Bluestone formation need to be investigated. Not only are marine invertebrates plentiful in parts of the Bluestone, but also a well-preserved flora of coal-forming plants is known to occur in the Hunt member.

FACIES

About eight fundamental facies are recognizable in the Mississippian of the Appalachian region. The general relationships of these facies have not received much study, but certain aspects of the general facies relations are obvious enough to be worthy of mention.

Red beds are prominent in the Mississippian of Pennsylvania. Some of the lower red beds, including the Patton[2] shale, are probably genetically related to the subjacent Devonian Catskill red beds. The Mauch Chunk represents a somewhat different facies, inasmuch as the beds are largely marine. Part of the Mauch Chunk of Pennsylvania is probably equivalent to some of the Greenbrier limestones exposed farther south in West Virginia. The Greenbrier limestones constitute a great sequence of limy beds which divide the Mauch Chunk facies into two parts, the extensions of which reach southward nearly to the Virginia-Tennessee line. The lower of these divisions (fig. 1) is the Maccrady; the upper is the thick Pennington-Princeton-Bluestone succession.

The coarse cross-bedded arkosic beds of the Pocono facies predominate in the lower Mississippian of Pennsylvania and as far south as the James River in Virginia. In the more southeasterly belts of outcrop, tongues of Pocono lithology persist as far south as the Virginia-Tennessee line; locally in New River Valley coal is mined from the Pocono facies, although the Grainger clastic

[2] The name "Patton shale," which appears in fig. 1 and on the Mississippian correlation chart (Weller *et al.*, 1948) is invalid, by reason of prior use of "Patton" for an older shale of Pocono age in western Pennsylvania.

marine facies predominates. In Smyth, Tazewell, and Washington counties, the Price-Grainger lithology prevails to the almost complete exclusion of the Pocono facies. Still farther southwestward, in the Cumberland Gap district, the Grainger lithology is supplanted by the Chattanooga black shale. The complementary relationship of the Grainger-Kimberling marine clastics, as developed in the Bluefield area, to the Chattanooga shale in the Cumberland Gap area is one of the most obvious facies changes in the Paleozoic sequence of the southern Appalachian region (fig. 2).

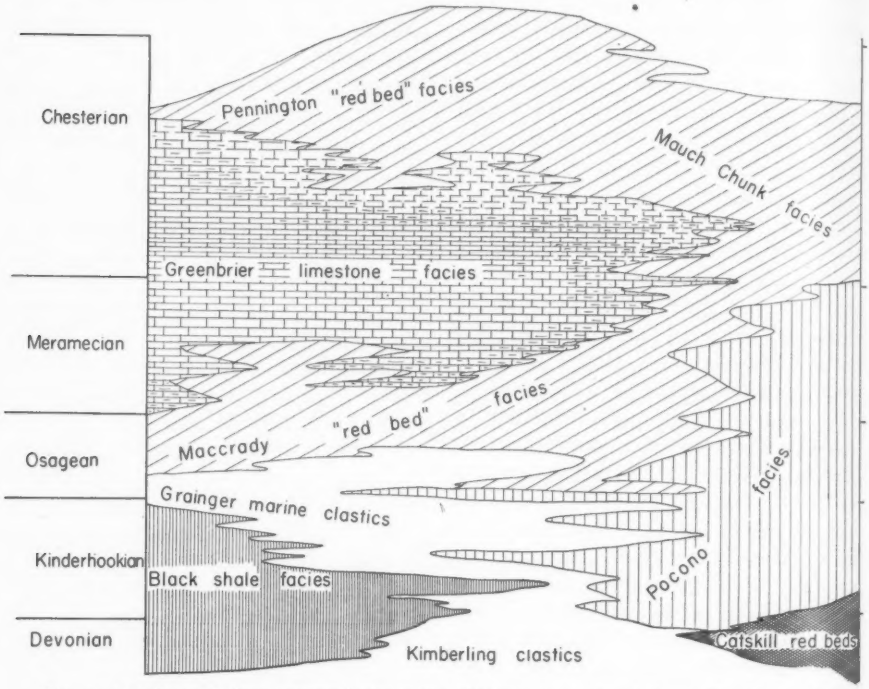


FIG. 2.—Idealized relations between facies in the Mississippian system between Harrisburg, Pennsylvania (*right*) and Cumberland Gap, Virginia (*left*).

The Greenbrier limestone magnafacies, with its maximum thickness in Virginia and West Virginia, is supplanted to the northeast by the Mauch Chunk and the Pocono. The time represented by the type Greenbrier is probably recorded in the Pocono and the Mauch Chunk of Pennsylvania (fig. 2). The Greenbrier limestone facies grades into the clastic facies above and below it not only by intertonguing but also by almost imperceptible lithologic transitions. Indeed, the entire Greenbrier facies is enclosed by a fringe of hybrid lithologies. The impure limestone above the Maccrady red beds and below the main body of Greenbrier limestone in the Greendale syncline of Washington County, Virginia, is a Maccrady-Greenbrier hybrid parvafacies. The Bluefield formation bears the same relationship to the Green-

brier and Pennington-Bluestone beds. The Loyalhanna limestone is a hybrid facies related to the Pocono and Greenbrier (fig. 2). The Cove Creek and Glen Dean limestones of Virginia are also hybrid facies related to the Pennington-Bluestone division.

The variations within each of these facies are very complicated. For example, the writer in the course of routine field investigations on the industrial possibilities of the Greenbrier limestones of southwestern Virginia came to recognize fourteen distinctive types of limestone, which are repeated at different stratigraphic levels. These parvafacies are not as difficult to separate as are those of the Grainger-Price-Pocono beds, which are the product of both marine and nonmarine deposition.

MISSISSIPPIAN SECTION IN THE GREENDALE SYNCLINE OF VIRGINIA

A summary of Mississippian stratigraphy should include mention of the amazing section which occurs in the Greendale syncline of Virginia (fig. 3). In many respects this succession is without an equal elsewhere in North America. More than half the 7,000-foot thickness is fossiliferous limestone. The general

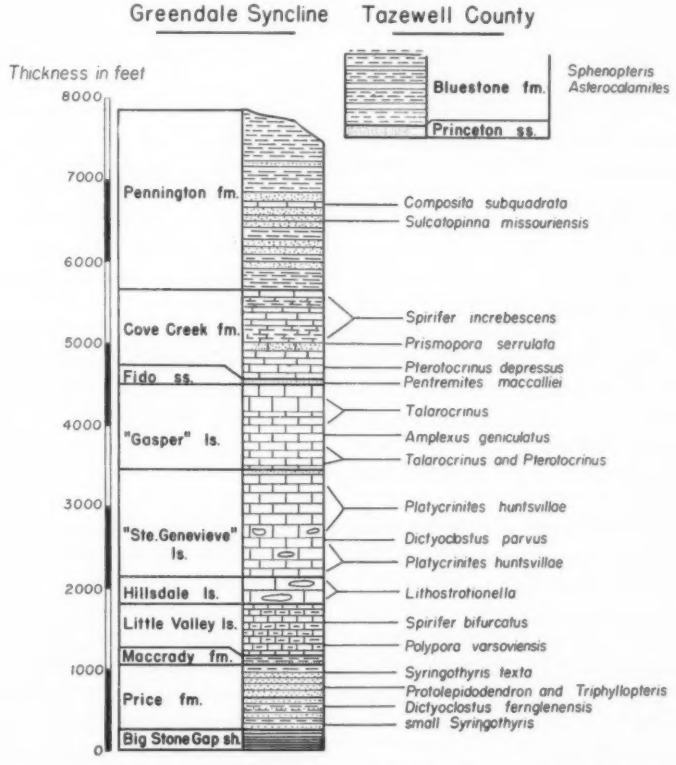


FIG. 3.—Mississippian formations in central-western Virginia

features of the section have been described by Butts (1940, pp. 337–340) and Averitt (1941); but most of the formations that they recognized are gross lithologic units.

At the base of the section is a post-Chemung black shale with *Lingula*, *Leiorhynchus*, and *Sporangites*. Succeeding this 60-foot unit is about 800 feet of Price sandstone with *Spirifer marionensis* and *Syringothyris sp.* in the lower part. Beds somewhat higher contain *Euphemites galericulatus* and *Dictyoclostus fernglenensis*, and the upper 200 feet contain *Pseudosyrinx* and *Orthotetes keokuk*. Above the Price are the Maccrady red beds, here very thin and containing *Polypora varsoviensis* and other Warsaw bryozoans. The overlying Little Valley limestone is about 700 feet thick and contains the same bryozoan fauna as is present in the subjacent Maccrady red beds and other Warsaw-Salem fossils, including *Camarotoechia mutata* and *Spirifer bifurcatus*.

The next unit is the Hillsdale limestone, with the ubiquitous guide *Lithostrotionella* indicating general equivalency to the St. Louis limestone of the Mississippi Valley. Above the 300-foot St. Louis equivalent are no less than 1,500 feet of limestone, which seem to be older than the Renault limestone (fig. 1) of the type Mississippian. The 1,500-foot division contains from top to bottom a profusion of stem plates belonging to *Platycrinites* of the type of *P. huntsvillae*, on which Butts (1940, pp. 372–374) relied heavily for identification of the Ste. Genevieve limestone. Other supposed Ste. Genevieve guides, including *Dictyoclostus parvus* and *Pentremites princetonensis*, also occur, but the precise range of the Ste. Genevieve fauna has not been determined.

The Ste. Genevieve limestone equivalent is overlain by 1,000 feet of limestone containing *Pterotocrinus* and *Talarocrinus* and also a coral, possibly the same as the Renault guide, *Amplexus geniculatus*. This "Gasper" limestone is overlain, in turn, by a thin ferruginous sandstone, the Fido, containing the giant blastoid, *Pentremites maccalliei*. This species is very closely related to the *Pentremites obesus* of the type Mississippian Golconda formation. This sandstone is followed by the 1,000-foot Cove Creek limestone, which abounds in Glen Dean fossils and carries the distinctive genus *Prismopora*—a guide to the Golconda-Vienna interval of the Mississippi Valley region. The Cove Creek limestone is overlain by Pennington-type sandstones and shales, with late Chester fossils in the middle portion of the 1,000–1,600 feet of the Pennington (fig. 3). If the Princeton and Bluestone formations of adjoining Tazewell County, Virginia, are younger than the Pennington beds of the Greendale syncline, then approximately 900 feet of beds must be added to complete a full composite section of the Mississippian system of southwestern Virginia.

In comparing the Mississippian section of the Greendale syncline with the type Mississippian, it is barely possible that a fuller depositional record is being compared to a less nearly complete, though better-known, section. At least, one can expect to find the faunas of the type Mississippian deployed through greater stratigraphic thicknesses in the central Appalachian region than in any other part of the United States. The attractiveness of the Mississippian succession of the Greendale syncline as a field for biostratigraphic and paleontological studies is enhanced by the almost continuous exposures along several main highways and by extensive glady areas

wherein well-preserved fossils are abundant.

SUMMARY

Although the Appalachian region received considerable study in the early days of reconnaissance mapping by the United States Geological Survey, the region has received relatively little detailed study. Most of the Appalachian faunas are still undescribed or only poorly known, and few attempts have been made to work out regional and local facies relationships in any of the Paleozoic systems. This unsatisfactory state of knowledge applies particularly to the Mississippian system, which contains many essentially untouched fields for stratigraphic and paleontological study. However, the same types of challenging problems pertain to the other Paleozoic systems of the Appalachian region. The progress of modern stratigraphic work in this region will continue to be exceedingly slow as long as paleontological studies are no more active than they have been in the past.

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SOME PROBLEMS IN MISSISSIPPIAN STRATIGRAPHY OF THE SOUTHERN APPALACHIANS[1]

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ABSTRACT

Mississippian stratigraphic problems of the southern Appalachians pertain to: (1) refinement in stratigraphic subdivision; (2) establishment of lateral relationships from one place to another, especially between disconnected areas and areas of independent previous study; (3) correlation of the southern Appalachian strata with the better-known units of the standard section; (4) establishment of the manner and time of origin of some of the units; and (5) establishment of the Mississippian-Pennsylvanian boundary. Examples of major problems which need further study are discussed. Solution of many of the stratigraphic problems must await careful and detailed field studies and, particularly in several instances, a consideration of the faunas.

It would be presumptuous for the writer to pose as an authority on the problems of Mississippian stratigraphy in the southern Appalachians, because his own researches have been confined to the Mississippian of the North-central Interior. Nevertheless, summer field courses on the Cumberland Plateau in eastern Tennessee, reconnaissance field excursions in the southern Appalachians, and perusal of the literature have acquainted him with some of the problems. However, only a few of the outstanding problems will be discussed. For the sake of brevity, no attempt is made to summarize the works of previous writers or to cite the literature in full. The author's responsibility, as he sees it, is to give a general summary of the problems of Mississippian stratigraphy in the southern Appalachian area.

Foremost among present-day needs is a refinement in stratigraphic subdivision, together with closer correlation. Many units, now recognized throughout much of the area, are thick and highly generalized. A good example is the Bangor (restricted) limestone, a generalized group of limestone beds of Chester age, 100–700 feet thick, which should be subdivided and related to the known divisions of the Chester series of the Mississippi Valley. The Chester of eastern Kentucky should be traced southward; and its fauna needs careful collecting and study. The Bangor group, as now defined, is a "restricted" survival of the original Bangor of the early literature which included all Mississippian strata above the Fort Payne chert. Later workers identified the St. Louis, Ste. Genevieve, and Gasper limestones in the lower part of the group and separated the Pennington shale from the topmost portion. The undifferentiated remainder is all that is now called "Bangor." A calcareous, ferruginous sandstone, locally present between the top of the Gasper and the base of the restricted Bangor, has been called "Hartselle." This sandstone is generally believed to be the age-equivalent of the Hardingsburg sandstone, although agreement on this point is not unanimous. According to Butts (1926), the Bangor "restricted" should be correlated with the combined Glen Dean, Tar Springs, Vienna, and Waltersburg beds of the standard section. These beds have not been differentiated in the southern Appalachians.

Another Mississippian problem in the

[1] Manuscript received February 7, 1948.

southern Appalachian area is the *lateral* relationship between the rock of a given outcrop belt and that in another belt not too far away. The lithological dissimilarity is, of course, a facies problem. The so-called "Floyd shale" affords an example. About midway between the eastern and western margins of the Valley and Ridge Province there are several outliers of this shale, up to 2,000 feet thick, which trend northeast-southwest across southern Tennessee, northwestern Georgia, and Alabama. This shale overlies the Fort Payne chert. The name "Floyd" has been abandoned in some localities where correlations with the standard section have been suggested. However, there remains considerable uncertainty as to the relationships in other localities. For example, in the Ringold and Chattanooga quadrangles, the Floyd shale is quite prominent along one belt, whereas a few miles to the west, shale is missing, and only a limestone facies is present. Butts (1926), in his excellent studies in Alabama, concluded that the "Floyd corresponds to the formation . . . from the base of the Gasper to the top of the Bangor, and probably extends as low as the base of the Ste. Genevieve." The age relationships between the rocks of these two belts are not clear and call for detailed field and faunal studies.

Toward the northern end of the mid-section of the Valley and Ridge Province in Tennessee is another thick shale, called the "Grainger," which lies above black, fissile shale and below so-called "Fort Payne chert." Like the Floyd shale, it, too, is absent in the sections at the western edge of the province a few miles away. Considerable uncertainty remains as to the stratigraphic relationship of the Grainger to the typical Chattanooga black shale farther southwest, the Olinger member of Swartz farther northeast, and other Mississippian strata at the plateau escarpment a short distance farther west, where the Grainger is absent. On the east side of the Valley and Ridge Province, lying directly against the boundary of the Older Appalachians, at the base of Chilhowee Mountain in the Knoxville quadrangle, is a little-known belt of shale and sandstone which also was called "Grainger" by Keith (1895). These beds, 1,000 feet thick, present one of the important, though smaller, problems in southern Appalachian Mississippian stratigraphy, that has received little study.

Even where attempts have been made to identify and to separate specific formations within generalized units, such as the Bangor, there is still considerable uncertainty in the placing of exact boundaries in the field. For example, at many exposures along the Cumberland Plateau or along the sides of the Sequatchie Valley, the exact contact between the St. Louis and the Ste. Genevieve has not been agreed upon; and the boundary between the latter and the Gasper is somewhat arbitrary and uncertain. Again, there is seen the need for a more thorough collecting and study of fossils.

The "black-shale problem" is a major one in the southern Appalachians, as it is elsewhere. The possible subdivision of the Chattanooga shale into members, the manner and time of origin of the sediments, and the relationships with the New Albany and Ohio black shales to the north and northeast in Kentucky, Virginia, Ohio, and Indiana constitute problems which are too large for full discussion in this paper. Many stratigraphers are, of course, familiar with the general Devonian-Mississippian age controversy of these black shales. After working in the Highland Rim of Tennessee, Klepser contends that the black-shale facies,

from southern Kentucky southward, extends into a much higher portion of the column, and he concludes that " . . . as the Chattanooga and overlying Maury everywhere grade upward into the overlying units of successively younger age southward, it must be concluded that the Chattanooga is a time-transgressing unit ranging from Kinderhook to Keokuk in age." Following an early suggestion of Grabau, he contends, in other words, that the shales represent the basal shore phase of a sea advancing slowly southward upon low-lying swampy land and that their northern time-equivalents are the normal, off-shore sediments of the New Providence and Fort Payne formations. Klepser presented his views in a doctoral dissertation (1937) and in a paper presented before the Tennessee Academy of Science in November, 1946. The absence of the New Providence shales in eastern Tennessee certainly calls for an explanation. In Kentucky, Ohio, and Indiana, the New Providence shale is a progressively northward-thickening wedge, which separates the black shale beneath from the younger Keokuk siltstones above. The microfaunas, especially the conodonts, have led various workers to suggest correlations between the subdivisions of the Chattanooga black shale in the southern Appalachians and the black shales farther north. The recent studies of W. H. Hass bearing on this question were summarized in the published abstracts of papers listed for the December, 1947, meetings of the Geological Society of America. In the abstract of his paper, entitled "The Chattanooga Shale Type Area," Hass stated:

> At the Apison locality, the upper black shale member contains lower Mississippian conodonts and is correlated with the Sunbury shale of Ohio. The lower black shale member contains conodonts that correlate it with the Huron shale of Ohio, a formation that the U.S. Geological Survey classifies as Upper Devonian. The middle gray shale member contains Huron conodonts, but its age is equivocal as J. H. Swartz has reported macrofossils from it which he considered to be of early Mississippian age. . . . The presence of Huron conodonts in the lower black shale member of the Chattanooga disproves the thesis, held by some workers, that, as a unit, the Chattanooga shale is younger than the black shale sequence of the North-Central States.

This line of reasoning, shared also by others, that identical or closely similar assemblages of microörganisms in deposits at widely separated localities prove the contemporaneous age of the sediments should, in the author's opinion, be carefully weighed against the thesis that a faunal assemblage might have persisted under a given environmental condition across a wide span of time. If all or but a part of the black shales in question, which stretch across hundreds of miles of territory, are a "magnafacies," or "phase," deposited in an environment which shifted slowly southward with the passage of time, is it not conceivable that a given assemblage of microörganisms favorable to a given set of paleoecological circumstances might have remained unchanged throughout a considerable span of time and might now be found as a fossil assemblage coextensive with the given lithologic, time-transgressing unit? Such a paleoecological, or facies-fauna, concept may resolve some of the stratigraphic perplexities which arise from field studies. Certainly, it is one that was impressed upon the writer by his own field studies of the Lower Mississippian formations of southern Indiana and the East-central Interior (1931, 1939).

The author's detailed studies of the Lower Mississippian strata of the East-central Interior, in Indiana, Kentucky,

and parts of adjoining southern Ohio, especially the great thickness of Osage shales and siltstones, leads him to ask certain questions about these rocks in the southern Appalachians: (1) Why are they missing to the south, and what happens to them in the concealed cover of the Appalachian Plateau? (2) Are the calcareous rocks of the Fort Payne formation of eastern Tennessee and northern Alabama and Georgia the time equivalents of the clastic sediments of the Borden group of Indiana, the New Providence, Brodhead, and Muldraugh of Kentucky, and the Cuyahoga and Logan of Ohio, or are these strata represented by a profound unconformity? (3) Where did these sediments come from?

Nearly everywhere in the southern Appalachians, the Fort Payne beds lie evenly upon the thin and persistent Maury shale with its phosphatic nodules, which, in turn, overlies the Chattanooga black shale. Above the Fort Payne and between it and the St. Louis (Meramec) limestone, in eastern Tennessee, occur some drab-colored siltstones with worm-trails and *Taonurus* markings. Because these strata weather readily, they are generally concealed and are little known. More recent workers have referred them to the Warsaw. Their relationships to the clastics to the north are not understood and need study. Certainly, these siltstones are lithologically similar to the Keokuk (Osage) siltstones of Kentucky. This brings up the classic Mississippian problem—the boundary between the Osage and the Meramec. In tracing the Mississippian rocks from Indiana southward and eastward across the Kentucky outcrop belt, the writer (1939) was impressed by the conspicuous unconformity at the base of the St. Louis, which transgresses underlying beds and leads to the gradual eastward disappearance of Warsaw strata. This relationship not only indicates the prominence of the break between the Osage and the Meramec groups but gives additional support to other field evidence that the Warsaw strata are more closely allied to the Osage than to the Meramec.

Nearly everywhere in the southern Appalachians, the Fort Payne chert lies in even beds upon the Chattanooga-Maury sequence. Recently, however, the writer found in the White Oak Mountain area an exposure of a large bioherm, composed of myriads of crinoids, projecting prominently upward into the Fort Payne. A careful study of this bioherm and search for others may contribute to the solution of the Fort Payne–Chattanooga age relationships. Such bioherms, which are well known in the Mississippian of the East-central Interior, have not before been reported from the southern Appalachians.

In a summary of the problems of the Mississippian stratigraphy, the problem of the Mississippian-Pennsylvanian boundary cannot be omitted. Whereas, throughout the greater part of the North American interior, a marked unconformity separates the two systems, such a physical break is missing, or is certainly not clear, throughout much of the southern Appalachians. In Alabama the Parkwood formation, 2,000 feet of shale and arkosic sandstone, closely resembles the overlying rocks of unequivocal Pennsylvanian age. Its lower part is believed to grade laterally into the Pennington shale in eastern Tennessee. In 1926 Butts wrote: "The Parkwood bridges the gap or unconformity that elsewhere in the Appalachian region intervenes between the Mississippian series and Pennsylvanian series." In eastern Tennessee the Pennington shale, which is uppermost Chester in age, is overlain by the Gizzard

formation of Pottsville age. Many fine exposures have been studied along the Cumberland escarpment at the eastern margin of the Appalachian Plateau, where a dearth of fossils and a gradual gradation upward from the clayey shales of the typical Pennington into the sandy shales of the Pottsville makes it impossible to indicate other than an arbitrary systemic boundary.

In this paper, the author has confined himself to the limitations of the title—*problems* in Mississippian stratigraphy of the southern Appalachians. Many of the solutions and answers rest with the future.

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SUBSURFACE CORRELATIONS OF LOWER CHESTER STRATA OF THE EASTERN INTERIOR BASIN[1]

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ABSTRACT

Direct comparison of logs of closely spaced wells and their assembly into cross sections appear to demonstrate a number of inconsistencies in the nomenclature that is currently applied to the lower part of the Chester series and to the Ste. Genevieve formation in different parts of the Eastern Interior Basin. This evidence indicates that: (1) the important oil-producing "Aux Vases" sand of the central basin area is equivalent to the outcropping Rosiclare sandstone member of the Ste. Genevieve formation; (2) the "Benoist" (Yankeetown), Bethel, and Sample sandstones are successively younger rather than correlative units; (3) the Cypress sandstone of Indiana and west-central Kentucky is younger than the Cypress of Illinois; (4) certain continuous limestone units can be traced between the various areas (the Beech Creek or "Barlow" limestone lies above the Illinois Cypress but beneath the Indiana Cypress); (5) the Downeys Bluff limestone, for a long time considered a part of the Renault formation because it lies below the Bethel sandstone, is in reality the basal Paint Creek limestone above the Yankeetown and is correlated with the upper portion of the Paoli limestone of Indiana; (6) the Levias limestone and part of the Shetlerville (Renault) together form a continuous limestone sequence which overlies both the "Aux Vases" of the basin and the Rosiclare sandstone of the outcrop area in southeastern Illinois.

INTRODUCTION

The intensive drilling program that began in 1937 when oil was discovered in the deeper part of the Eastern Interior Basin has produced a wealth of stratigraphic data on the Mississippian formations above the St. Louis limestone. Almost all locations within the Illinois Basin proper (the deepest part of the Eastern Interior Basin) are within 2 miles of wells or tests for which good stratigraphic records are available. Thus a re-examination of the long-range correlations made at the beginning of the basin oil development appears in order.

The fund of information on the variation in stratigraphy indicated by subsurface records provides material not only for subsurface correlation but also for a new attack on the perplexing problems of outcrop correlation around the border of the basin area.

This paper records the stratigraphic columns in current use in different parts of the Eastern Interior Basin for the Mississippian strata between the St. Louis formation of the Meramec group and the Hardinsburg sandstone of the Homberg (middle Chester) group. Correlation between the several areas is indicated by a chart (fig. 1). The chart is substantiated by the cross sections (figs. 3–6) whose locations are shown on the index map (fig. 2). The conclusions are similar to those of Dana and Scobey (1941) but are here presented in greater detail.

Although this report indicates the need for a revision of the standard classification of the lower part of the Chester series, this revision is not attempted here. It is postponed, awaiting clarification of several problems involving the correlation of formations defined in the southwestern Illinois and Missouri outcrop area with the units which can be traced throughout the rest of the basin.

CORRELATION CHART

The left-hand column of the correlation chart (fig. 1) has been slightly modified since the Chester rocks in south-

[1] Published by permission of the Chief, Illinois Geological Survey, Urbana, Illinois. Manuscript received May 20, 1948.

western Illinois were described by S. Weller (1913, p. 120); its present form is that used by Cooper (1941, p. 7). The formation boundaries as originally given by Weller are in current use and appear to be applied consistently throughout the outcrop area, which extends along the Mississippi River for 85 miles below St. Louis. This area is west of the limits of the index map (fig. 2).

The second column gives the usage applied by members of the Illinois Basin Oil Scouts Association in the Louden, Salem, Boyd, and Woodlawn oil fields of south-central Illinois and in the area west of these fields. Boyd (fig. 2) is near the eastern edge of the area in which this nomenclature is consistently used.

The third column shows the nomenclature applied by the geologists of oil companies operating in the lower portion of the drainage basin of the Wabash River in Illinois and Indiana. Maunie and New Haven, Illinois, are in this area (fig. 2).

The fourth column of figure 1 shows the names applied in the fluorspar area of Hardin County, Illinois, and adjacent parts of Illinois and Kentucky by S. Weller (1920*b*, pl. 1), as modified by J. M. Weller and Sutton (1940, p. 766), and Atherton (1948, p. 129). Golconda, Illinois, is in this region (fig. 2).

The names currently applied in oil fields in Henderson and Daviess counties, Kentucky, are indicated in the fifth column of figure 1. Poole oil field (fig. 2) is near the heart of this area.

The sixth column is the outcrop section in west-central Kentucky given by Stouder (1941, p. 25), and the last column is the outcrop section in Indiana given by Malott (1931, p. 222 and 1946, pp. 322–326). Leavenworth, Indiana (fig.

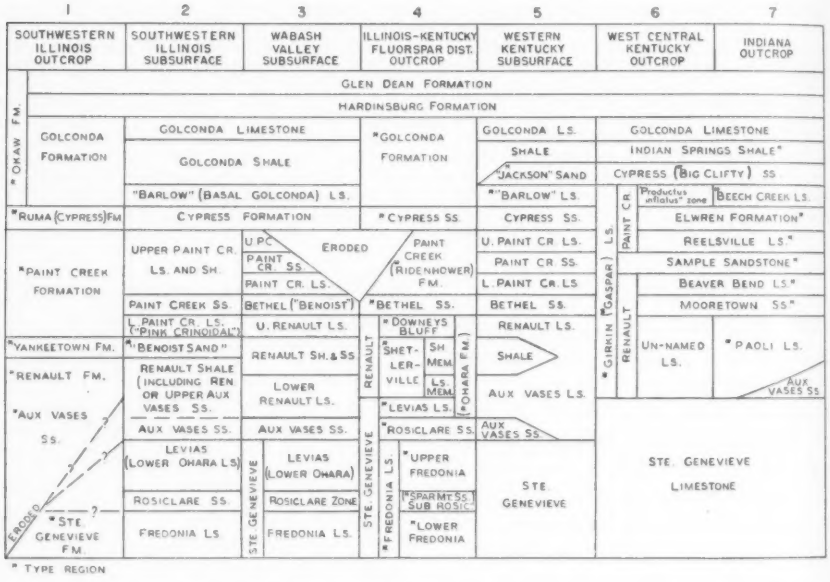


FIG. 1.—Correlation of middle Chester, lower Chester, and Genevieve strata in Eastern Interior Basin

FIG. 2.—Index map of part of Eastern Interior Basin, showing wells and outcrops used in cross sections

2), lies in the outcrop belt of southern Indiana and west-central Kentucky which is described by Malott and Stouder.

The correlations between the first and second columns of figure 1—the southwestern Illinois outcrop and subsurface areas—are not represented by a cross section. As indicated by Tippie (1943), these correlations are commonly accepted in this region. They are further discussed in the stratigraphic section of this report under "Beech Creek limestone," "Downeys Bluff limestone," and "'Benoist' (Yankeetown) sandstone."

CROSS SECTIONS

The geologic cross sections (figs. 3–6) pass through wells nowhere more than 11 miles apart and averaging less than 2 miles apart. Most sections were compiled from electric logs. Although only a few major lithologic types can be indicated on the figures, minor distinctions in lithology were used throughout the study to guard against errors in correlation between adjacent wells. The original cross sections were drawn on a vertical scale of 20 feet to 1 inch. Twelve to fourteen different physical types of rock were classified by their electrical characteristics, and the electric-log interpretations were checked by sample studies wherever there appeared to be any possibility of miscorrelation. All cross sections have a vertical exaggeration of 211.

Figures 3, 4, and 5 have been prepared by using the base of the Downeys Bluff limestone as the datum plane. Figure 3 substantiates the correlations indicated between the second and third columns of figure 1 and shows that the "Benoist" (Yankeetown) and the Bethel sandstones are not continuous. Figure 4 shows that the terminology used for the lower part of the stratigraphic section in the Wabash Valley oil fields is a full sedimentary cycle lower than that applied to the same beds in the outcrop area of southeastern Illinois. Figure 5 carries the correlation from the Wabash Valley to the heart of the western Kentucky oil fields across the barrier of continuous Bethel-Sample-Cypress sandstone deposition.

Figure 6 has been prepared with the Beech Creek or "Barlow" limestone as a datum plane. This has been done because the Downeys Bluff, which is readily distinguishable throughout Illinois and the adjacent portions of Indiana and Kentucky, becomes difficult to differentiate from the other beds of the Paoli limestone as the Indiana-Kentucky outcrop belt is approached. This cross section extends from the western Kentucky oil-field district to the Indiana outcrop belt, substantiating the correlations indicated between the fifth column and the last two columns of figure 1. The Beech Creek or "Barlow" limestone is shown to underlie the Big Clifty or Cypress sandstone of the Indiana section and to overlie the Illinois Cypress. The Bethel sandstone of western Kentucky is equivalent to the Mooretown sandstone rather than to the Sample sandstone of the outcrop belt. Figure 6 shows the entire Chester series rather than just the lower portion, as seen in the preceding cross sections. It indicates clearly the character of the pre-Pennsylvanian surface and the regular thinning of most Chester units toward the eastern outcrop belt. The correlations of the upper part of the Chester series demonstrated here agree with those given by Malott (1931, p. 222). The Indiana names for this part of the section have been virtually abandoned in favor of their western correlatives.

The logs of fluorspar tests[2] in Living-

[2] H. H. Cronk, superintendent of the Rosiclare Lead and Fluorspar Mining Company, and P. L. Richards, superintendent of the Inland Steel Com-

Fig. 3.-

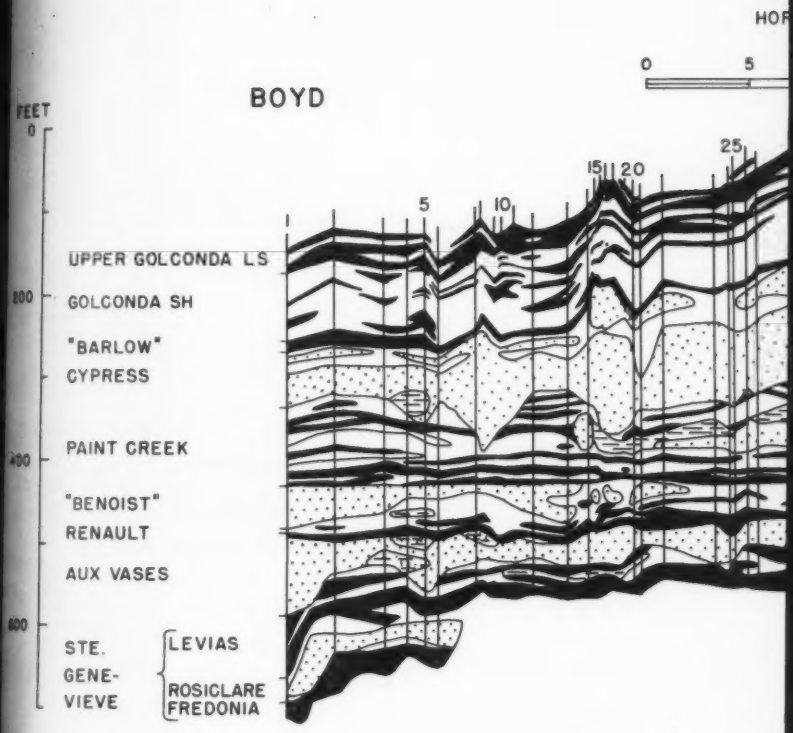
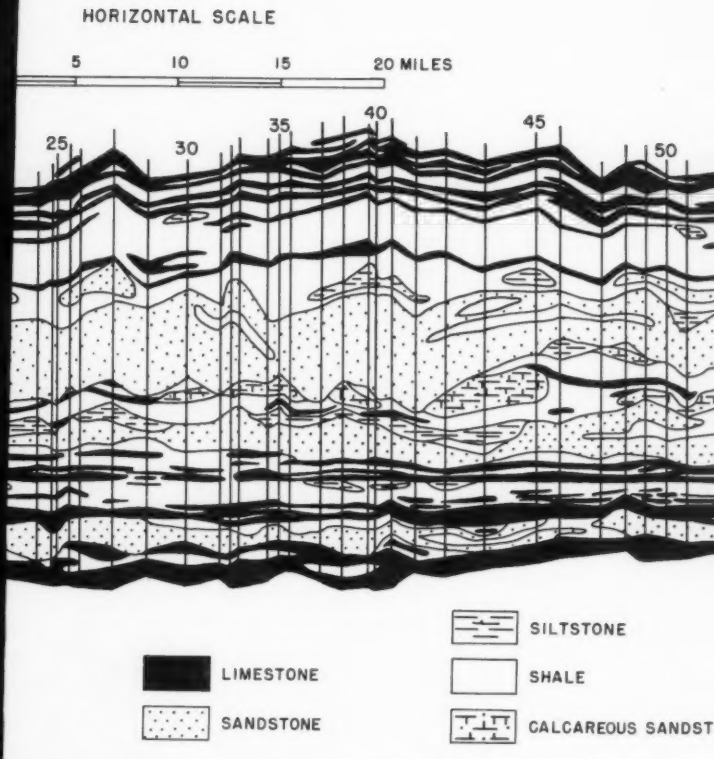
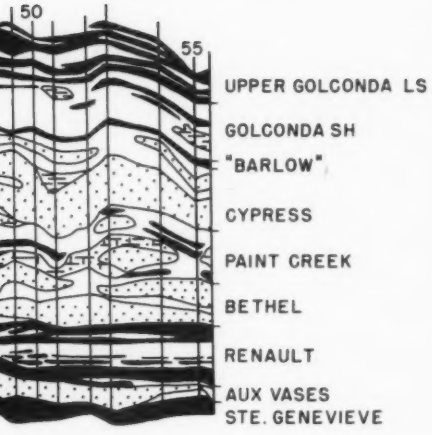


FIG. 3.—Cross section of lower Chester strata between oil fields of southwestern Illinois near Boyd



s near Boyd and Wabash Valley oil fields near New Haven, Illinois (see fig. 1, cols. 2 and

NEW HAVEN



S SANDSTONE

, cols. 2 and 3). Well lines omitted in congested portions

0 5 10 15 20 MILES

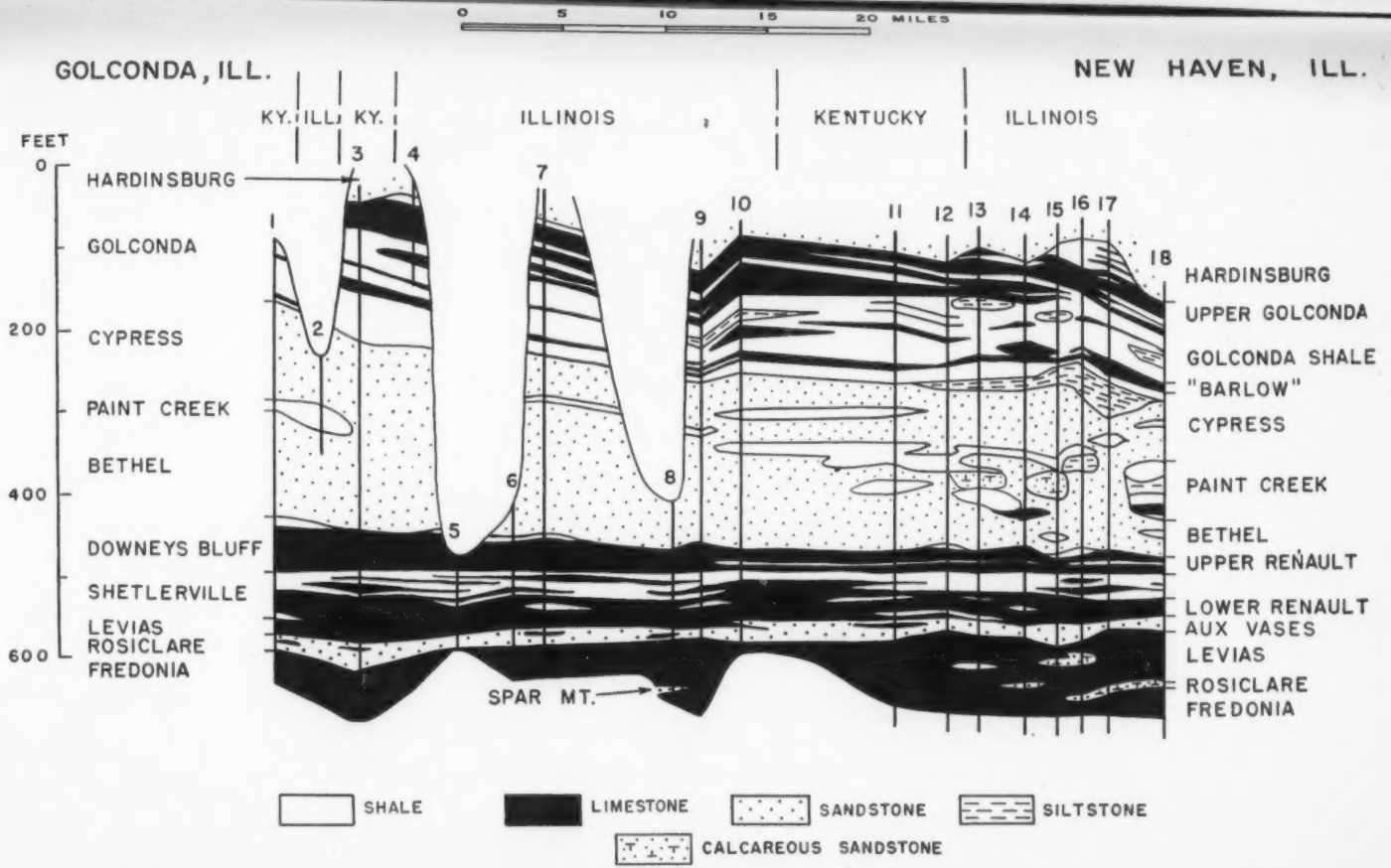


FIG. 4.—Cross section of lower Chester strata between outcrops in the Illinois-Kentucky fluorspar district near Golconda and the Wabash Valley oil fields near New Haven, Illinois (see fig. 1, cols. 4 and 3).

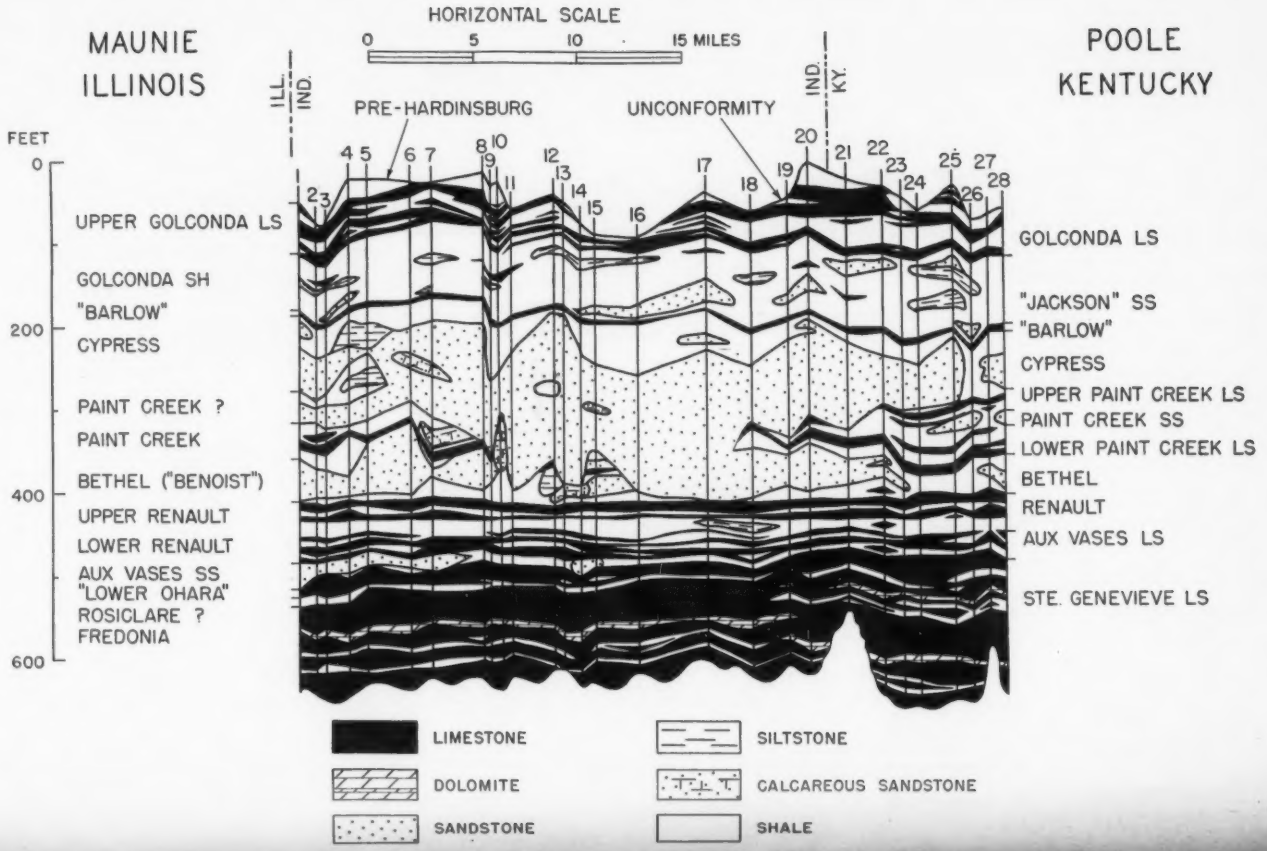


FIG. 5.—Cross section of lower Chester strata between the Wabash Valley oil fields near Maunie, Illinois, and the western Kentucky oil fields near Poole (see fig. 1, cols. 3 and 5).

FIG. 5.—Cross section of lower Chester strata between the Wabash Valley oil fields near Maunie, Illinois, and the western Kentucky oil fields near Poole (see fig. 1, cols. 3 and 5).

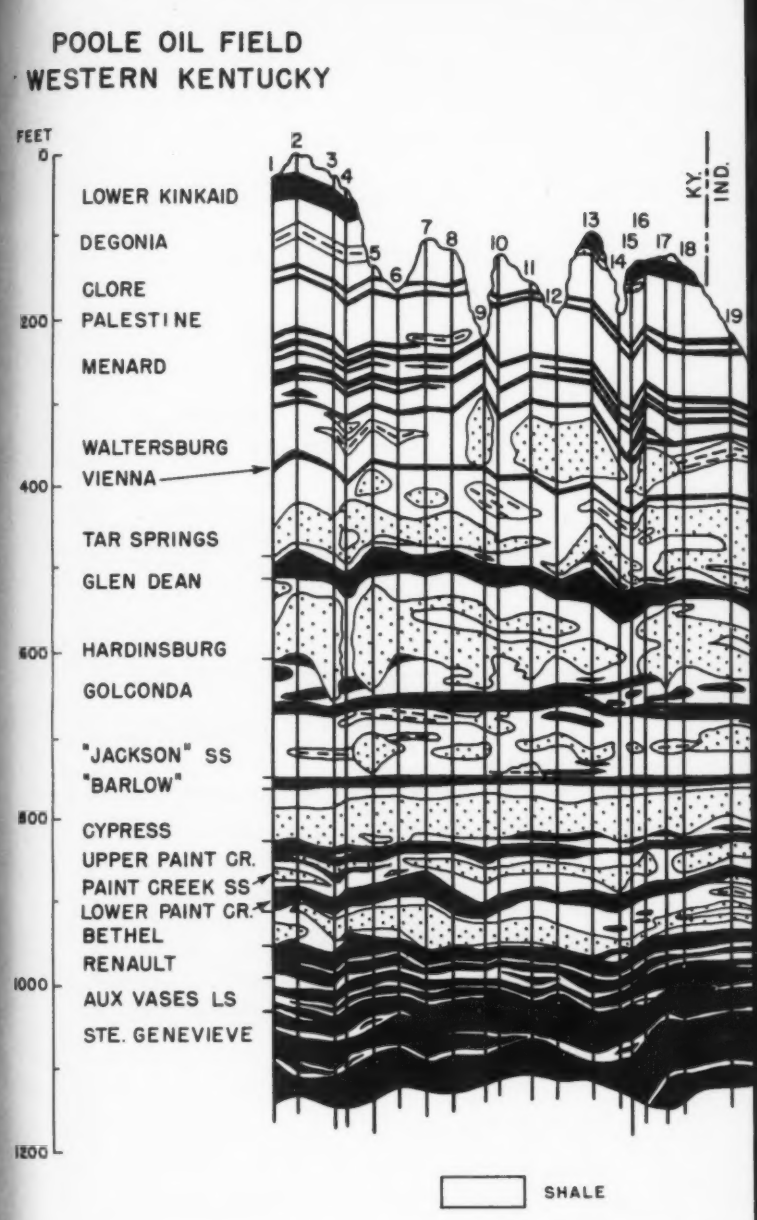
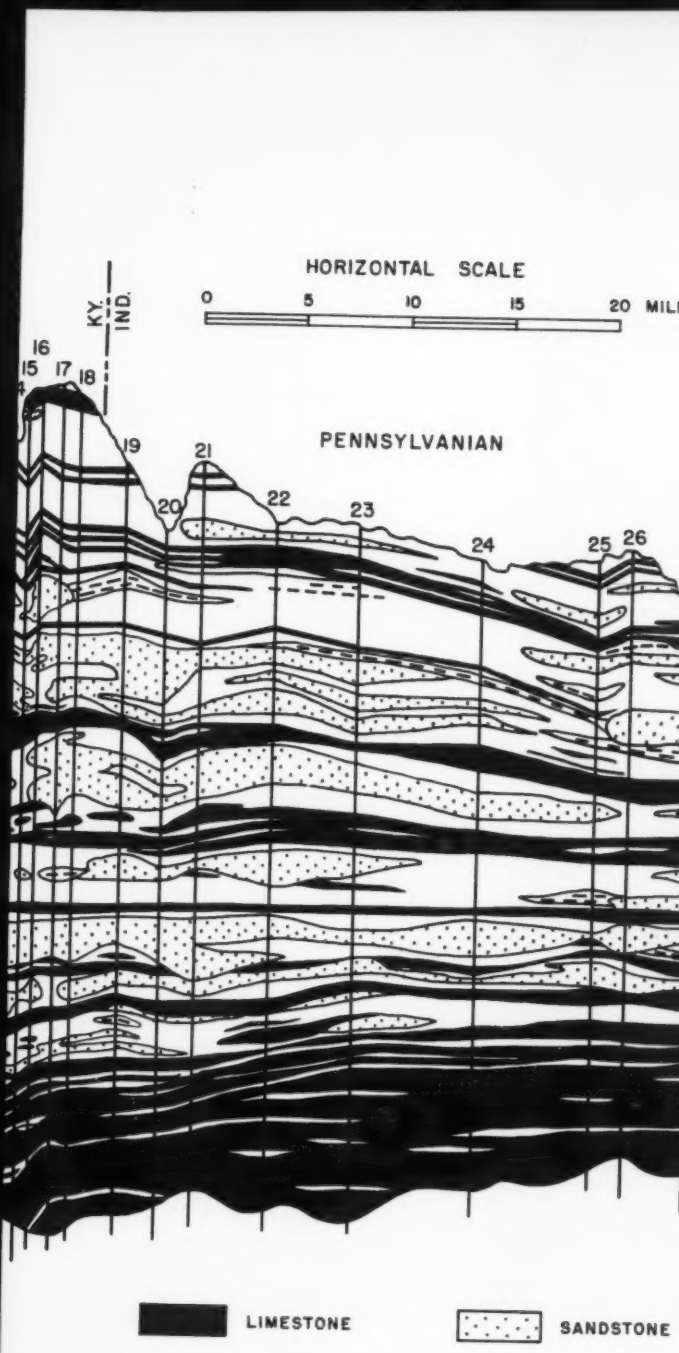
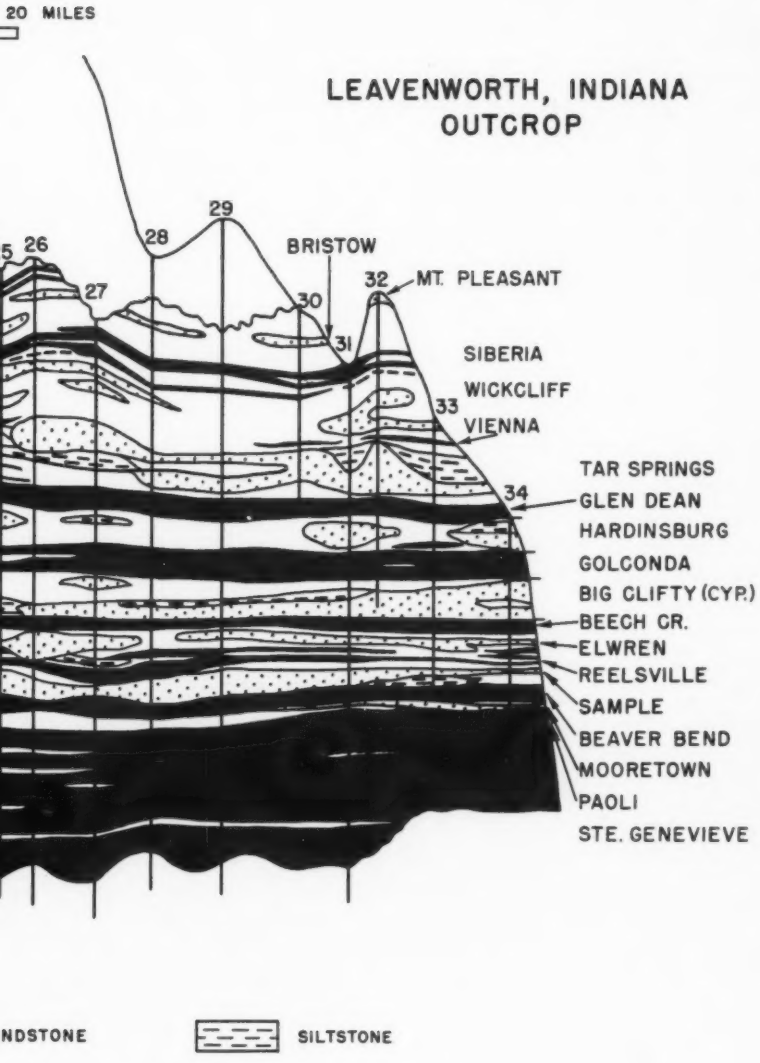


FIG. 6.—Cross section of Chester strata between western Kentu



n western Kentucky oil fields near Poole and the Indiana-Kentucky outcrop belt at I



rop belt at Leavenworth, Indiana (see fig. 1, cols. 5 and 7)

ston County, Kentucky, and Hardin County, Illinois, used in figure 4 are based on descriptions by Gill Montgomery of the Minerva Oil Company and by several members of the Illinois Geological Survey. Section 2 of figure 4 is that given by S. Weller (1920, p. 168); section 4 of this figure was measured by L. E. Workman and published by Atherton (1948, p. 128); sections 5 and 6 have been described in several publications on the stratigraphy of the fluorspar district; and log 8 was used by Tippie (1945, p. 1657). Logs 28 and 29 in figure 6 are given by Logan (1931, pp. 461, 466). Section 30 in figure 6 is from Malott (1925, p. 125). Sections 32, 33, and 34 were measured by Swann.[3] All other logs used in the cross sections are sample studies by Atherton, electric logs interpreted by Swann, or composite sample and electric logs.

STRATIGRAPHY

Inasmuch as there is general agreement in the correlation and nomenclature used within the Eastern Interior Basin for units above the Golconda formation, the uppermost formation which is considered here is the Hardinsburg sandstone which overlies the Golconda. Stratigraphic units are described in descending order. No attempt is made to place the units in formations, groups, or series, and the text headings are not intended to imply stratigraphic rank.

HARDINSBURG SANDSTONE

The Hardinsburg sandstone has its maximum development in an area extending from Hamilton and Lawrence counties, Illinois, on the northwest to the outcrop belt through Crittenden and Christian counties, Kentucky, on the south, and to Daviess County, Kentucky, on the east. In this area it lies unconformably on the Golconda formation. Local relief of the pre-Hardinsburg surface is as much as 60 feet in a few localities; channels 10–30 feet deep are quite common (figs. 4, 5, and 6). These narrow channels may be traced for only short distances and appear to die out at either end and do not seem to be connected into valley systems. The thickest known section of Hardinsburg (more than 200 feet) includes about 50 feet of sandstone filling such a channel. Within its region of greatest development the formation is typically 50–70 feet thick; but at a few localities in this same area only 20 feet of gray and varicolored shale with silty laminae separate the massive Glen Dean and Golconda limestones.

Most of the Hardinsburg formation consists of very fine and fine angular light-gray sandstone, greenish siltstone, and gray to black shale. These rocks are present in varying proportions and different successions in localities within a few hundred feet of each other. In the region of its maximum thickness the sandstone is separated from the overlying Glen Dean limestone at almost all localities by a few feet of greenish to dark-gray shale. This shale above the Hardinsburg and below the massive limestone beds of the Glen Dean becomes varicolored and contains dolomite and limestone lenticles as it is traced away from the region of thick Hardinsburg. Within the general region of thick Hardinsburg there are many disconnected areas in which soft gray and greenish shales as much as 30 feet thick, containing occasional red streaks and brown sublithographic dolomite lenses, lie between undisputed Hardinsburg sand-

pany, Fluorspar Division, kindly released the information on which composite log 7 in fig. 4 is based. J. H. Steinmesh, president of Minerva Oil Company, kindly released logs 1, 3, 9, and 10 of fig. 4.

[3] Field notes, 1947.

stone and massive Golconda limestone (figs. 4, 5, and 6). To the west, north, and northeast this shale becomes more persistent and includes more dolomite and more red, green, and purplish shales. In these peripheral areas this lower shale is overlain in apparent conformity by the feather edge of the typical Hardinsburg sandstone-siltstone–dark-shale unit. In the parts of the Illinois Basin farthest from the Hardinsburg center, the sandy facies is not developed and the massive Glen Dean and Golconda limestones are separated by only 12–40 feet of varicolored shales containing dolomite and occasional limestone lenses. The sandstone-siltstone–dark-shale unit extends to the outcrop along the southern and eastern margins of the basin, but, in general, only varicolored shale is present at the western, northern, and northeastern borders.

The general practice among oil companies is to place the boundaries of the Hardinsburg formation at the base of the massive Glen Dean limestone and at the top of massive thick-bedded, light-colored oölitic or crystalline limestone of Golconda age, thus including the varicolored shales and brownish dolomites as well as the sandy phase in the Hardinsburg formation (Dana and Scobey, 1941, p. 876). The formation boundaries as thus designated are probably contemporaneous over most or all of the basin and follow horizons which can be identified consistently both in the area of maximum development where channel cutouts occur and in the peripheral areas of apparent conformity. If this practice is followed, the episode or episodes of channel-cutting are placed in the middle rather than at the beginning of Hardinsburg time, since it is apparent that the unconformable surface lies above both the shale-and-dolomite facies and the massive Golconda limestone.

If the name "Hardinsburg" is restricted to the sandy facies (and this has historical precedence), the time of channel-cutting is placed at or near the beginning of Hardinsburg time, and the formation name is limited to genetically related lithologies. Varicolored shale above the sandy phase of the Hardinsburg was originally placed in the Glen Dean formation (Butts, 1917, p. 97). Because it weathers readily, the shale beneath the Hardinsburg sandstone rarely crops out; sandy strata have been reported to rest directly on massive Golconda limestone wherever the contact is visible. The Illinois Geological Survey places this lower shale-and-dolomite zone in the Golconda formation (Workman, 1940, p. 816; Folk and Swann, 1946, p. 11), though it is recognized that the boundaries of the sandstone facies to which the name "Hardinsburg" is thus restricted may not be contemporaneous throughout the basin.

The Hardinsburg has been described in detail because it presents a number of features common to the lower sandstone units in the Chester and the Ste. Genevieve strata. In the lower beds these features are in part obscured and there are disagreements concerning correlation, whereas in the Hardinsburg there is no correlation problem. In those areas in which the Chester sandstones are coarsest and thickest, they rest on conspicuous surfaces of unconformity which are clean and not deeply weathered and in which valley systems have not been noted. Surrounding these areas are belts in which the sandstones are thinner and finer and lie with apparent conformity between shale beds, many of which are in part red, green, and purple. Still farther from the areas of maximum thickness, the sandstones are replaced entirely by shales, which may be fossiliferous and contain limestone or dolomite beds.

GOLCONDA FORMATION, UPPER SHALE AND LIMESTONE

At the top of the Golconda formation is the unnamed, gray, green, and red shale interbedded with thin lithographic dolomite, which has been described in the preceding section.

Underlying the unnamed shale unit, or in direct contact with the Hardinsburg sandstone, where the shale has been removed by pre-Hardinsburg erosion, is a prominent limestone, generally called "the Golconda lime" and more specifically described as "the massive upper Golconda limestone" by petroleum geologists. It is equivalent to the entire Golconda formation as recognized in the outcrops of Indiana and west-central Kentucky but to only a part of the formation as recognized in the type area in southern Illinois and in western Kentucky. White, light-gray, and light-tan crystalline or crinoidal limestone and dolomitic limestone, gray to tan oölitic limestone, and gray shaly limestone predominate. Oölitic beds are common in the western part and cherty limestones in the eastern part of the basin. In some localities this member is nearly all limestone, but within a short distance it may grade to 50 per cent or more gray shale. It is 40–50 feet thick in the south-central part of the basin, and it thins slightly but retains its essential limestone character to the eastern and western outcrops. It thins markedly toward the north and becomes very shaly, so that, at its northernmost subsurface occurrences, it can hardly be distinguished from the underlying Indian Springs shale.

INDIAN SPRINGS SHALE

Underlying the massive upper Golconda limestone in the central parts of the Eastern Interior Basin is a third member of the Golconda, a shale 60–100 feet thick, containing minor amounts of limestone, siltstone, and sandstone. The unit is commonly known only as "the Golconda shale," but a representative of the upper part has been named the "Indian Springs shale." The most common rock in this unit is a weak gray shale which weathers readily to a light-colored or olive mud in outcrops and which caves badly in well borings. Red shale is common toward the top of this zone. Siltstones occur at several levels in southernmost Illinois but farther north are confined to the middle and lower portions. They do not occur in western Illinois. Several types of limestone occur in thin beds or lenses that increase in number and importance from eastern to western Illinois. In the west a 5–15-foot bed of red and yellow mottled, fossiliferous, crystalline limestone is a persistent marker near the middle of the member. The upper portion of this shale becomes so limy at the western edge of the Illinois Basin that its contact with the overlying limestone member is obscure.

In Indiana and Kentucky there is very little limestone in this shale unit, and the lower part is replaced by the sandstone known locally as "Jackson" in the subsurface and "Cypress" on the outcrop, described below as the "Big Clifty sandstone." The upper portion of the shale unit extends over the Big Clifty to the Indiana outcrop belt, where it has been named the "Indian Springs shale" by Malott and Thompson (1920, p. 521).

BIG CLIFTY SANDSTONE

Sandstone lenses occur sporadically in the lower part of the Golconda (Indian Springs) shale as far west as Marion County, Illinois, 60 miles from the Wabash River. The lenses are rather uncommon in Illinois, but eastward they are more abundant and coalesce into a continuous sandstone unit which apparently has its maximum thickness in a

belt extending through eastern Gibson County, Indiana, and Daviess County, Kentucky. There are places in this area at which the sandstone is more than 100 feet thick and lies on an unconformable surface which cuts into and even through the Beech Creek limestone. This is the most continuous and most prominent sandstone in the lower and middle Chester of the Indiana and central Kentucky outcrop belt. Its maximum outcrop thickness, 55–70 feet, is in Hardin, Breckinridge, and Grayson counties, Kentucky, where it caps the Dripping Springs escarpment (Stouder, 1941, p. 48). The name "Big Clifty" was applied to this sandstone in this area by Norwood (1876, p. 369). The name has been little used because this prominent sandstone has generally been considered equivalent to the Cypress sandstone, which had been previously named in southern Illinois. Northeast of a line extending approximately from Shawneetown, Illinois, through Dixon and Greenville, Kentucky, the Big Clifty is separated from the true Cypress by a sheet of Beech Creek ("Barlow") limestone, continuous except for very narrow channels from which it was removed by pre–Big Clifty erosion. Southwest of this line along the outcrop belt through Christian and Caldwell counties, Kentucky, the Big Clifty may lie directly on the true Cypress. It seems likely that even in this area there may be scattered remnants of the Beech Creek separating the two sandstones, as was suggested by Ulrich (1917, p. 94).

BEECH CREEK ("BARLOW") LIMESTONE

A thin, but widespread and readily recognized, limestone is the basal unit of the Golconda formation and has been named the "Barlow" line in the subsurface section of Kentucky. It is a dark-brown to dark-gray limestone which in many localities is mottled. Scattered sand grains and very dark-colored limestone granules are common; in some localities there are true oölites. The limestone is commonly very fossiliferous. It contains a diverse fauna in which small brachiopods and mollusks predominate. Polished sections of cores show numerous small gastropods, but the compact matrix makes the fauna difficult to identify. Other types of limestone may be a associated with the dark-colored dense bed, in most cases overlying it.

The "Barlow" line extends across the basin from east to west, appearing in the lower part of the Okaw limestone in southwestern Illinois and as the Beech Creek limestone of Indiana. Unlike other Chester limestones, it thickens consistently toward the north. In the lower Wabash Valley its thickness averages about 8 feet, but it is 20–30 feet thick in the northernmost parts of the basin, where it is by far the most prominent Chester limestone.

The "Barlow" thins southward until it cannot be recognized in many wells in southern Webster and Hopkins counties, Kentucky, or in Saline, Williamson, and even Franklin counties, Illinois. It is present in possibly half the diamond-drill cores from the Illinois-Kentucky fluorspar district as described by trained geologists familiar with its appearance. It is seldom noted in other types of subsurface records from this area and has not been recognized in the poorly exposed outcrops of the lower Golconda shales. In the diamond-drill core used for log 1 of figure 4 it is represented by less than 3 feet of dark, very shaly limestone.

The light-colored, coarsely crystalline limestone containing large crinoid stems which forms approximately the upper three-fourths of the Beech Creek lime-

stone of Indiana can be traced for some distance as the upper portion of the "Barlow," but it is much less persistent than the dark-brown basal portion.

The base of the "Barlow" is the most widely used horizon for contour maps of Illinois Basin areas. It is now generally considered the base of the Golconda formation.

CYPRESS SANDSTONE

The Cypress sandstone has its greatest thickness in the south-central part of the Illinois Basin, where it may be more than 200 feet thick. Because in this area it rests on other similar sandstones, its true thickness may never be known. It is predominantly white fine- to medium-grained sandstone and gray siltstone and shale. One or two thin coal beds occur sporadically near the top of the formation. Lateral changes from sandstone to shale are very common. The top part, 30–50 feet thick, is commonly more shaly than the lower part of the formation, but beds of sand may occur at any position up to the very top. A zone of red and green shale and green siltstone occurs at the top of the Cypress throughout a wide belt surrounding the region of greatest thickness. Along the extreme eastern and western borders of the basin the entire unit may be replaced with varicolored shale. Although the uppermost shale zone has been placed in the Golconda formation (Brokaw, 1916, pl. 1; Workman, 1940, p. 216), the current tendency is to include it with the Cypress, as it is commonly interbedded with thin sandstone beds. The varicolored shales equivalent to the true Cypress have been named "Ruma" (S. Weller, 1913, p. 126) in southwestern Illinois and "Elwren" (Malott, 1919, p. 11) in Indiana. The Cypress rests unconformably on lower formations, except possibly in the most northern and eastern parts of the basin.

PAINT CREEK (RIDENHOWER) FORMATION

Approximately midway between the persistent Beech Creek ("Barlow") limestone and the equally persistent Downeys Bluff limestone, there occurs a discontinuous zone which is composed of diverse rock types and has a maximum thickness of 100 feet. This zone has been described as three formations—the Reelsville limestone, Sample sandstone, and Beaver Bend limestone in Indiana (Malott, 1919, pp. 9–11); as a single formation—the Ridenhower shale in southeastern Illinois (Butts, 1917, p. 73); and as part of the Paint Creek formation in southwestern Illinois. Although single units within this zone may be traced a number of miles, it is difficult to characterize the zone as a whole. Several factors have shared in producing the complex stratigraphy of this zone. Pre-Cypress erosion removed the zone entirely in some localities and reduced its thickness in many areas. The Cypress sediments deposited on the eroded surface are, in some places, similar to the beds removed. There is at least one pronounced unconformity within the zone. Rapid lateral and vertical changes in deposition can be demonstrated in a number of single outcrops.

There is a belt 10–20 miles wide extending north-northeast from the vicinity of Marion and Uniontown, Kentucky, toward Washington, Indiana, in which the entire column between the "Barlow" and the Downeys Bluff is occupied by sandstone (fig. 5). It is probable that the Indiana classification of three units can be followed rather consistently between the east side of this belt and the region in south-central Kentucky where all clastics disappear from the section. Available data from the belt of thick sandstone do not show any clear break between the

pre-Cypress unconformity and the base of the Bethel, so it is not certain that both Bethel and Sample sandstones are present, although this seems probable. It also is not evident whether the Beaver Bend and Reelsville limestones were deposited and later eroded from this area or were never deposited here.

In the subsurface section of Illinois west of the continuous sandstone belt, the application of a threefold division of the Paint Creek above the Bethel is much more difficult than in Kentucky and Indiana. The division is suggested in some logs shown in figure 3. Certain geologists who have studied intensively the area north of logs 30–50 of this section recognize beneath the pre-Cypress unconformity a "gray limestone" (Reelsville?) which has generally been removed by erosion, a shale and micaceous sandstone zone (Sample?), a "yellow limestone" (Beaver Bend?), a blastoidal shale, and the Bethel. The unconformity cuts across all these strata, so that the Cypress may rest directly on the Bethel. The writers are unable to distinguish these zones in their work in Lawrence and Edwards counties, Illinois; therefore, they recognize only a single zone, which consists primarily of dark greenish-gray shale with variable proportions of fine-grained calcareous sandstone and sandy fossiliferous, partly oölitic limestone. In western Illinois this zone becomes more calcareous and is represented in the Paint Creek outcrop belt by as much as 50 feet of limestone.

BETHEL SANDSTONE

The Bethel sandstone has its greatest thickness east of the area of maximum Cypress sandstone, locally measuring 100 feet or more. It contains some quartz-pebble conglomerate, but the formation usually consists of more or less calcareous light-gray, very fine to fine-grained sandstone with some medium-grained sandstone. Dark-gray to green shale containing laminae of siltstone is quite common. The type locality near Marion, Crittenden County, Kentucky, is probably within the belt of continuous Bethel-Cypress or Bethel-Sample-Cypress sandstone described above (Butts, 1917, p. 63; 1929, p. 46).

To the north and west of the area of maximum thickness the formation becomes thinner, more shaly, more calcareous, and fossiliferous. The writers know of only a single outcrop of the Bethel in southwestern Illinois. It is a calcareous fossiliferous sandstone a few feet above the deep-red nonlaminated shale member of the Paint Creek formation in the NE. corner of the SE.$\frac{1}{4}$ and NE.$\frac{1}{4}$ of Sec. 23, T. 5 S., R. 9 W., about 2 miles east of Prairie du Rocher, Randolph County. This locality was noted by Stuart Weller in his report on the "Geology of Parts of Monroe and Randolph Counties."[4] In the rest of the southwestern Illinois outcrop area the position of the Bethel is occupied by varicolored calcareous shales that in some localities are highly fossiliferous.

The sandstone phase of the Bethel continues to the eastern outcrop, where it is known as the "Mooretown sandstone" (Cumings, 1922, p. 515) and includes thin but persistent coal streaks overlain by a few feet of dark-gray shale. The "limestone" indicated in the Bethel position in log 22 of figure 6 is probably calcareous sandstone; several sandstones in this well had abnormally high apparent resistivity, and samples were not available for comparison. As is true with most Chester sandstone units, the Bethel is recognized by its relation to the as-

[4] Illinois Geological Survey, unpublished manuscript.

sociated limestone beds rather than by any inherent characteristics.

DOWNEYS BLUFF LIMESTONE

A persistent limestone which is useful in correlating lower Chester beds has been named the "Downeys Bluff" by F. E. Tippie (Atherton, 1948, p. 129). The type locality is in the Ohio River bluff at Rosiclare, where the limestone underlies the Bethel sandstone and overlies the Shetlerville limestone and shale. In southwestern Illinois these beds consist of bluish calcareous shales with platy, fine-grained limestone layers lying between the deep-red nonlaminated shale member of the Paint Creek and the Yankeetown chert. This zone was described by S. Weller (1913, p. 125; 1920*a*, p. 294) as the basal member of the Paint Creek formation. Two other kinds of rock are found in this zone in the western outcrop belt. One is a yellowish, crystalline, crinoidal limestone. The other is a characteristic light-gray, coarsely crystalline, fossiliferous, and somewhat sandy limestone in which numerous blastoid and crinoid plates are in part replaced by a bright-pink or salmon-colored chert. Replacement of colored crinoid plates by pink or red chert is not known in other lower Chester formations. The gray limestone with pink chert fossils can be seen in the outcrops along a branch of Carr Creek in the NE.$\frac{1}{4}$, Sec. 33, T. 1 S., R. 10 W., about 2 miles south of Columbia, Monroe County, Illinois. It is recognized throughout the subsurface section of southwestern and south-central Illinois, and the entire Downeys Bluff is known by the informal name "Pink Crinoidal" throughout Illinois. In eastern Illinois the bulk of the Downeys Bluff is a light-brown to gray crinoidal limestone, the upper part cherty and the lower part slightly sandy. Pink to red chert is reported in some wells in eastern Illinois and even in Indiana (Dana and Scobey, 1941, p. 879). Throughout most of eastern Illinois and western Kentucky and Indiana the Downeys Bluff may be recognized by a very characteristic double-peaked resistivity curve on the electric log. The saddle has been interpreted in figures 5 and 6 as a thin shale, although it may be an argillaceous limestone. The Downeys Bluff is represented in the Indiana outcrop by the upper part of the Paoli limestone.

"BENOIST" (YANKEETOWN) SANDSTONE

All the sandstones considered so far are prominent beds in the eastern or south-central parts of the Eastern Interior Basin; on the southwestern Illinois outcrop they are represented by, at most, a few feet of impure sandstone. In contrast, Chester and Ste. Genevieve sandstones below the Downeys Bluff limestone (with a possible minor exception) are best displayed near the western margin of the basin.

The uppermost of these western sandstones has been named the "Benoist" sandstone in Sandoval oil field, Marion County, Illinois, about 15 miles north of Boyd. The stratigraphic section at Sandoval is very similar to that shown in figure 3, log 1. In this area the "Benoist" is separated from the "Pink Crinoidal" or Downeys Bluff limestone by a very few feet of green shale. Continuous cores show that immediately above or interbedded in the top foot or two of the "Benoist" are thin beds (nodules?) of a brown siliceous limestone, which grades into, or is replaced by, chert. Westward this zone at the top of the "Benoist" can be traced into at least some of the outcrops of the Yankeetown chert (Tippie, 1943, p. 141). Swann agrees with Weller and Sutton (1940, p. 826, ftn. 19) that

the Yankeetown includes residual chert from several horizons, and therefore he hesitates to apply the outcrop term to the sandstone. The "Benoist" is typically 40–60 feet thick where best developed, but it rests directly on continuous Renault or Aux Vases sandstone in many localities where its true thickness cannot be determined.

Eastward from its area of maximum thickness the "Benoist" thins rapidly, and in easternmost Illinois it consists only of about 20 feet of dark-gray, green, and red shale, in the upper part of which occur lenses of calcareous light-gray, red, or greenish fine-grained sandstone or siltstone. The lower part of this shale is interbedded with layers of brownish-gray argillaceous, fossiliferous limestone and grades downward into the main body of Shetlerville limestone. The entire sequence was named the "Shetlerville formation" by S. Weller (1920*a*, p. 290), and the shale and the sandstone are now called "Middle Renault" by most operators in the Wabash Valley oil fields. East of the Wabash the sandstone is absent. Its position is indicated by 2–3 feet of fossiliferous shale near the middle of the Paoli limestone at the more northern of the Indiana outcrops; but even this shale is lacking in the southernmost Indiana and Kentucky occurrences of the Paoli.

SHETLERVILLE LIMESTONE

The lower portion of the Shetlerville formation is predominantly limestone, grayish-brown in color, oölitic, fossiliferous, argillaceous, and in many places sandy. Oölites with dark centers are common; and red, pink, olive, and yellow oölites occur. The Shetlerville in Illinois is quite impure, as is indicated by the insoluble residues described by Tippie (1944, p. 157); but it apparently becomes purer in Indiana and Kentucky, where it forms the lower portion of the Paoli limestone. It makes up the bulk of the "Lower Renault" limestone of the oil fields in the deeper part of the basin.

LEVIAS LIMESTONE

The Levias limestone of the fluorspar district is a high-purity oölitic or crinoidal limestone containing coarse pink crinoid fragments and, at its base, minor amounts of sand. It may be traced northward from the outcrop to Lawrence County, Illinois, as a thin, light-gray or pink oölite at the base of the "Lower Renault" (Shetlerville) limestone. It is not known to be more than 15 feet thick in the subsurface of the basin and is absent from many localities. As this bed contains columnals of *Platycrinus penicillus* in the outcrop area, it is placed in the Ste. Genevieve formation. However, it overlies a continuous sandstone horizon which can be traced north and west to a point where nearly 200 feet of sandstone and shale are present beneath what appears to be the position of the type Levias (figs. 3 and 4).

ROSICLARE ("BASIN AUX VASES") SANDSTONE

The Rosiclare sandstone of the fluorspar outcrop district of southeastern Illinois and western Kentucky is an extremely fine-grained sandstone which approaches siltstone in grain size. It continues to the north with similar lithology and is productive in many oil fields in Hamilton, Wayne, and White counties in southeastern Illinois, where it is called the "Aux Vases" sandstone. It is sometimes distinguished from the coarser-grained sandstones of western Illinois by the title "basin Aux Vases." Because of its fine grain size and resultant high connate water retention, it is characterized by abnormally low electrical resistivity

TABLE 1

Wells Used in Cross Section between Boyd Oil Field, Jefferson County Illinois, and the Vicinity of New Haven in the Wabash Valley (Fig. 3)

Index No.	State, County (Illinois)	Operator	No. and Farm	Spot or Footage	Sec., T., R.
1	Jefferson	D. Schwab *et al.*	1 Hutchings-Haldorson	NE. SE. NW.	36-1S.-1E.
2	Jefferson	T. B. Dirickson	1 Miller	NE. NE. NE.	18-2S.-2E.
3	Jefferson	E. J. Ruwaldt	1 W. J. Hynes	NW. SW. NW.	28-2S.-2E.
4	Jefferson	A. W. Gerson	1 W. B. Horton	SE. SE. NW.	27-2S.-2E.
5	Jefferson	Magnolia Pet. Co.	1 Bullock Unit	NW. NW. SE.	34-2S.-2E.
6	Jefferson	H. H. Wegener	1 Grant Comm.	W. NW. SE.	35-2S.-2E.
7	Jefferson	N. Redwine	2 Howard-Casey	SE. NE.	6-3S.-3E.
8	Jefferson	N. Redwine	1 K. Gee	NE. SW. SE.	6-3S.-3E.
9	Jefferson	Magnolia Pet. Co.	1 Badgett	NE. NW. SE.	7-3S.-3E.
10	Jefferson	Magnolia Pet. Co.	1 Daniels Unit	SW. SW. SW.	8-3S.-3E.
11	Jefferson	W. I. Lewis	1 Schul	SE. SE. NW.	9-3S.-3E.
12	Jefferson	Texas Co.	1 N. Cowger	NW. NW. NW.	11-3S.-3E.
13	Jefferson	J. V. Canterbury	1 L. S. Kent	NW. NE. SE.	12-3S.-3E.
14	Jefferson	Canterbury & Gill	1 R. Ross	SE. SE. SE.	7-3S.-4E.
15	Jefferson	Phillips-Gussman	1 R. E. Sheppard	C. SE. SE.	8-3S.-4E.
16	Jefferson	B. Martin *et al.*	1 Rittermeyer	SE. SW. NE.	9-3S.-4E.
17	Jefferson	C. E. Brehm	1 Burnett-Shelton Comm.	SE. SW. SW.	3-3S.-4E.
18	Jefferson	Gulf Refining Co.	1 Homer	SW. SE. NW.	3-3S.-4E.
19	Jefferson	Kewanee Oil & Gas	2 Derringer	N. NE. SE.	2-3S.-4E.
20	Jefferson	Tidewater Assoc. Oil Co.	"B"-1 Newton Investment Co.	N. NE. SW.	1-3S.-4E.
21	Jefferson	Magnolia Pet. Co.	1 F. R. Johnson	N. NE. SE.	1-3S.-4E.
22	Wayne	Lario Oil & Gas	1 R. Dodge	E. NE. NE.	7-3S.-5E.
23	Wayne	C. Crosby & Witt	1 Murphy	E. SW. NE.	15-3S.-5E.
24	Hamilton	Seaboard	1 G. Knapp	N. SW. SW.	22-3S.-5E.
25	Hamilton	Seaboard	2 D. Garrison	N. SW. NW.	27-3S.-5E.
26	Hamilton	Gulf Refining Co.	1 F. Zellers	SE. NW. SE.	27-3S.-5E.
27	Hamilton	Exchange Oil Co.	"A"-1 E. Silliman	SW. NW. NW.	35-3S.-5E.
28	Hamilton	Oil Carriers	1 T. Rose	SW. NE. SE.	36-3S.-5E.
29	Hamilton	Magnolia Pet. Co.	"A"-1 Kaufman	SE. SE. NW.	7-4S.-6E.
30	Hamilton	Magnolia Pet. Co.	1 Haas (Heil)	NW. NW. SW.	16-4S.-6E.
31	Hamilton	Oil Management *et al.*	1 Leach & Gilpin	C. SW. NE.	14-4S.-6E.
32	Hamilton	Phillips Pet. Co.	1 Holla	NW. NW. NE.	13-4S.-6E.
33	Hamilton	Phillips Pet. Co.	1 Wilma	SE. SW. NW.	7-4S.-7E.
34	Hamilton	Texas Co.	3 Flannigan	NE. SE. SW.	17-4S.-7E.
35	Hamilton	Texas Co.	2 Minton Comm.	SW. NE. NE.	20-4S.-7E.
36	Hamilton	Texas Co.	3 S. Minton	NE. NW. SW.	21-4S.-7E.
37	Hamilton	Oldfield & Spires	2 York	NE. SE. SE.	22-4S.-7E.
38	Hamilton	Oil Management *et al.*	1 J. Keith	NW. NW. SE.	26-4S.-7E.
39	Hamilton	Kingwood Oil Co.	1 Swadier	NE. NW. SE.	2-5S.-7E.
40	Hamilton	Kingwood Oil Co.	1 McGuire	W. SW. NW.	11-5S.-7E.
41	Hamilton	Lomelino & Williamson	1 Biggerstaff	NE. SE. NW.	14-5S.-7E.
42	Hamilton	T. Harvey	1 Wilson	NE. SE. SW.	23-5S.-7E.
43	Hamilton	B. M. Heath	1 Klemm Heirs	C. NE. SE.	35-5S.-7E.
44	White	National Assoc. Pet. Co.	1 A. Dalby	SE. SW. NE.	6-6S.-8E.
45	White	Gossett & Swensen	1 Justice	SE. NW. NE.	20-6S.-8E.
46	White	Luttrell	1 T. Aud	NE. NE. SE.	21-6S.-8E.
47	White	J. Reznik	1 Mills	NE. SW. NW.	35-6S.-8E.
48	White	Sinclair-Wyoming	1 A. Cobbell	SW. SW. SW.	36-6S.-8E.
49	White	Gulf Refining Co.	1 J. Moore	SW. SW. NW.	12-7S.-8E.
50	White	Kingwood Oil Co.	1 P. Martin	NW. SW. NE.	13-7S.-8E.
51	White	Sinclair-Wyoming Oil Co.	1 C. E. Wilson	SW. NE. SE.	18-7S.-9E.
52	Gallatin	Skelly *et al.*	1 H. H. Hale	NE. NE. NE.	21-7S.-9E.
53	Gallatin	Murphy Oil *et al.*	1 Spence	N. NE. NW.	33-7S.-9E.
54	Gallatin	N. V. Duncan	1 Greer	SE. SE. SE.	35-7S.-9E.
55	Gallatin	R. L. Kinkaid	1 A. B. Schmidt	NE. NE. NW.	33-7S.-10E.
56	Gallatin	Hageman & Pond	1 Stofleth-Cokes	NE. NE. NW.	34-7S.-10E.

for Illinois Basin sandstones. This electrical characteristic is indicated both on logs run in the basin and on a log run on a typical fluorspar exploration hole in Hardin County, Illinois. The sandstone is calcareous and variable in color; red sandstone is common where the formation is not productive, but the productive sand is very light colored, nearly white.

The Rosiclare shows considerable lateral changes within a very short distance and includes numerous lithologic types—siltstone, shale, sandy limestone, and dolomite—in addition to sandstone. Some sandstone beds contain very small, light-brown, round limestone grains and grade laterally to sandy oölitic limestone. Hematite-ringed oölites are characteristic of the zone, and a basal detrital conglomerate is present at many points. The Rosiclare ("basin Aux Vases") sandstone of southeastern Illinois appears, at least superficially, to grade imperceptibly into the thicker and coarser Aux Vases sandstone of the oil fields on the western flank of the basin, as is indicated by figure 3. The possibility of a transgressive overlap of western coarse-grained Aux Vases sandstone on eastern fine-grained "basin Aux Vases" is recognized; but the evidence supporting this interpretation is not conclusive, and further study is necessary.

TABLE 2

WELLS AND OUTCROPS USED IN CROSS SECTION FROM GOLCONDA, ILLINOIS TO NEW HAVEN, ILLINOIS (FIG. 4)

Index No.	State and County	Operator	No. and Farm	Spot or Footage	Sec., T., R.
1	Ky., Livingston	Minerva Oil Co.	DD 1 Robinson	7,200 WL., 10,550 NL. quad.	7-J-14
2	Ill., Pope	Outcrop at Golconda		SE. NW.	30-13S.-7E.
3	Ky., Livingston	Minerva Oil Co.	2 O. Morton	5,150 WL., 7,550 SL. quad.	17-K-14
4	Ill., Pope	Outcrop at Rock Quarry School		SE.	5-13S.-7E.
5	Ill., Hardin	Outcrop at Shetlerville		NE. SW.	35-12S.-7E.
6	Ill., Hardin	Outcrop at Downeys Bluff (Rosiclare)		NW. SE.	5-13S.-8E.
7	Ill., Hardin	Rosiclare Lead & Fluorspar Mining Co.	Ac 2 Fee	SE. SE. NW.	32-12S.-8E.
		Hillside Fluorspar Mines	107-D Fee	NW. NW. SE.	29-12S.-8E.
8	Ill., Hardin	Victory Fluorspar	126 Fee	NE. SE.	33-11S.-9E.
9	Ill., Hardin	Minerva Oil Co.	1 C. M. Austin	SW. SW. NE.	26-11S.-9E.
10	Ill., Hardin	Minerva Oil Co.	7 U.S. Forest Service	SE. NE. SE.	24-11S.-9E.
		Minerva Oil Co.	7 Milligan	CW. line, NW. NE. SW.	19-11S.-9E.
11	Ky., Union	H. H. Weinert	1 Union Trust Co.	N.½ N.½ N.½	22-O-18
12	Ky., Union	Sohio Prod. Co. *et al.*	2 Boswell	SE.	14-O-18
13	Ill., Gallatin	Cherry & Kidd	1 Gray	NE. NE. SE.	15-9S.-10E.
14	Ill., Gallatin	Sinclair-Wyoming	1 E. Hines	SE. SE. NW.	3-9S.-10E.
15	Ill., Gallatin	Sohio Prod. Co.	2 Nat. Resources	SW. SW. SW.	28-8S.-10E.
16	Ill., Gallatin	Carter	2 Jordan	NE. SE. NE.	21-8S.-10E.
17	Ill., Gallatin	Cherry & Kidd	12 Kerwin	SW. SW. SW.	11-8S.-10E.
18	Ill., Gallatin	Hagemann & Pond	1 Stofleth-Cokes	NE. NE. NW.	34-7S.-10E.

FREDONIA LIMESTONE

The Fredonia limestone of the fluorspar district includes beds equivalent to

the entire sequence called "Ste. Genevieve" in the eastern Illinois oil fields (fig. 4). The Fredonia is mainly limestone, oölitic, slightly sandy, light-gray, buff, or brown, and medium to coarse textured. Porous oölitic zones are known as "McClosky," although the upper two such zones are designated the "Lower O'Hara pay" and the "Rosiclare pay" by many geologists in the eastern Illinois oil fields. Many beds may be traced accurately over short distances, but long-range correlations within the mass of limestone are very difficult because of rapid lateral variation and the recurrence of similar lithologic types at different levels in the section.

Sandy zones occur at many horizons and may grade laterally into sandstone. One such sandy zone has been named the "Spar Mountain sandstone" by Tippie (1945, p. 1658) at a locality about 1 mile

TABLE 3

WELLS USED IN CROSS SECTION FROM VICINITY OF MAUNIE, ILLINOIS, TO POOLE OIL-FIELD AREA, HENDERSON CO., KY. (FIG. 5)

Index No.	State and County	Operator	No. and Farm	Spot or Footage	Sec., T., R.,
1...	Ind., Posey	Gulf Refining Co.	1 Aldrich Community	SE. NE. NE.	8-6S.-14W.
2...	Ind., Posey	Paul Maier	1 Aldrich	C. NE. NE.	4-6S.-14W.
3...	Ind., Posey	Morgenstern Oil Co., Inc.	1 Mentzer	NW. SW. NE.	34-5S.-14W.
4...	Ind., Posey	Justrite Drilling Co.	1 French	CW.½ W.½ W.½	1-6S.-14W.
5...	Ind., Posey	B. M. Heath	1 Noble Utley	SE. NE. SW.	30-5S.-13W.
6...	Ind., Posey	Milton A. Lobree C. E. O'Neal *et al.*	1 W. Jackson	NW. NW. NW.	27-5S.-13W.
7...	Ind., Posey	Paul Rossi	1 Kincheloe & Williams	NE. NE. NW.	35-5S.-13W.
8...	Ind., Posey	Gulf Refining Co.	3 Lang	SE. NE. SE.	6-6S.-12W.
9...	Ind., Posey	Nelson Development Co.	1 Horstman	NE. SE. NE.	7-6S.-12W.
10...	Ind., Posey	Gulf Refining Co.	1 Reineke	NE. SE. NW.	8-6S.-12W.
11...	Ind., Posey	L. E. Butzman *et al.*	1 B. R. Juncker	NW. NW. NW.	9-6S.-12W.
12...	Ind., Posey	S. C. Yingling	1 Eckhoff	SE. NW. SE.	21-6S.-12W.
13...	Ind., Posey	Ward-Larson	1 Eickhoff-Wolf	SW. NE. SW.	22-6S.-12W.
14...	Ind., Posey	Fleming & A. K. Swann	1 John Hartmann	NW. NW. SE.	27-6S.-12W.
15...	Ind., Posey	E. T. Wix	1 E. Miller	NW. SE. SW.	26-6S.-12W.
16...	Ind., Vanderburg	Justrite Drilling Co.	1 Miller	N.½ SE. NW.	31-6S.-11W.
17...	Ind., Vanderburg	Roy Lee, Trustee	1 Oakland City College	E.½ SE. SW.	3-7S.-11W.
18...	Ind., Vanderburg	Sun Oil Co.	1 Adcock Unit	NE. SE. SE.	23-7S.-11W.
19...	Ind., Vanderburg	C. E. O'Neal & Co.	1 Kuester	NE. SW. NE.	3-8S.-11W.
20...	Ind., Vanderburg	Calvert-Willis & Delta	1 Simmons	NW. NW. SE.	10-8S.-11W.
21...	Ky., Henderson	Basin Drilling Co.	5 Carl Smith	8,890′ NL., 9,810′ EL. quad.	8-P-23
22...	Ky., Henderson	Sohio Producing Co.	1 Bartley	6,900′ SL., 7,950′ WL. of quad.	17-P-23
23...	Ky., Henderson	Herndon Drilling Co.	1 Barrett	2,900′ SL., 11,250′ EL. quad.	23-P-23
24...	Ky., Henderson	Carter Oil Co.	1 Ben Rudy	4,500′ NL., 11,250′ WL. quad.	3-O-23
25...	Ky., Henderson	W. F. Bilsky	1 F. P. Royster	13,600′ SL., 12,300′ EL. quad.	13-O-23
26...	Ky., Henderson	Sohio Producing Co. & W. E. Hupp	1 Minton	6,800′ SL., 7,500′ WL. quad.	17-O-23
27...	Ky., Henderson	Carter Oil Co.	6 S. T. Denton	1,290′ SL., 5,670′ EL. quad.	22-O-23
28...	Ky., Henderson	Sohio Producing Co.	1 O. Royster 95A.	3,150′ SL., 400′ WL. quad.	25-O-24

south of the well illustrated in log 8 in figure 4. The sequence of minor lithologic types above the sandstone at this point is very similar to that above the "Rosiclare" in certain of the southeasternmost Illinois oil fields. In other areas different sand zones appear more prominent, and it is probable that different zones are called "Rosiclare" in different parts of the basin. Sandstones are much more common to the west, and in certain areas as many as three thick "Rosiclare" sandstones can be recognized, reaching 100 feet in total thickness. One moderately thick sandstone is indicated at the western edge of figure 3.

TABLE 4

WELLS AND OUTCROPS USED IN CROSS SECTION FROM POOLE OIL-FIELD AREA HENDERSON CO., KY., TO LEAVENWORTH, CRAWFORD CO. INDIANA (FIG. 6)

Index No.	State and County	Operator	No. and Farm	Spot or Footage	Sec., T., R.
1	Ky., Henderson	Sohio Producing Co.	1 O. Royster 95A.	3,150 SL., 400 WL. quad.	25-O-24
2	Ky., Henderson	Cherry & Kidd	1-A L. Eakins	300 EL., 200 NL. sec.	4-N-24
3	Ky., Henderson	Cherry & Kidd	1 T. J. Pritchett	1,050 EL., 2,950 SL. sec.	19-O-24
4	Ky., Henderson	Sohio Producing Co.	1 H. J. Knight	8,400 SL., 550 EL. quad.	20-O-24
5	Ky., Henderson	Ryan Oil Co.	1 V. Crafton	3,700 SL., 1,600 EL. sec.	9-O-24
6	Ky., Henderson	National Assoc. Pet. Co.	1 Williams	3,300 NL., 4,470 EL. sec.	1-O-24
7	Ky., Henderson	Carter Oil Co.	1 H. P. Barrett	5,880 SL., 4,650 WL. quad.	25-P-25
8	Ky., Henderson	Kingwood Oil Co.	1 Jones	7,380 WL., 6,900 SL. quad.	17-P-25
9	Ky., Henderson	Reznik	1 Moss	1,750 WL., 1,900 SL. sec.	7-P-25
10	Ky., Henderson	Sinclair Prairie Oil Co.	1 Hatchett	12,500 NL., 9,550 EL. quad.	12-P-25
11	Ky., Henderson	J. H. Williams	1 J. L. Overby	8,000 EL., 700 NL. quad.	2-P-25
12	Ky., Henderson	McCummings Oil Co.	1 E. Allen	1,950 SL., 2,300 WL. sec.	5-P-26
13	Ky., Henderson	Kentucky Producers Corp.	1 O. Breitschere	10,250 EL., 100 SL. quad.	23-O-26
14	Ky., Henderson	Coaster Co.	1 Haynes	5,600 EL., 5,950 SL. quad.	22-O-26
15	Ky., Henderson	Farmer & Chenault	1 R. E. Dunbar	9,260 SL., 3,240 EL. quad.	20-O-26
16	Ky., Henderson	Farmer & Chenault	1 M. Bruck	12,950 SL., 1,850 WL. quad.	15-O-27
17	Ky., Daviess	Sohio & Hupp Pet.	3 Reno Heirs	2,750 NL., 800 EL. sec.	14-O-27
18	Ky., Henderson	Farmer & Chenault	1 Bower & Heppler	4,400 WL., 9,600 NL. quad.	6-O-27
19	Ind., Warrick	W. Chenault	1 Turner	Approx. C. SW. SE.	36-6S.-9W.
20	Ind., Warrick	Ohio Oil Co.	1 R. Jones	NE. NE. SW.	20-6S.-8W.
21	Ind., Warrick	Eureka Oil Co.	1 T. H. Helms	SW. SW. NW.	23-6S.-8W.
22	Ind., Warrick	Sunlight Coal Co.	1 Hart	SE. SE. NW.	27-5S.-8W.
23	Ind., Warrick	Cherry & Kidd (Ashland Oil)	1 Verona Coal Co.	SW. SE. SW.	8-5S.-7W.
24	Ind., Warrick	L. T. Phillips	2 T. S. Phillips	NE. NE. SW.	32-4S.-6W.
25	Ind., Spencer	Texas Co.	1 Hanning	SW. SW. NE.	2-5S.-5W.
26	Ind., Spencer	Texas Co.	1 Gogel	SE. NW. SW.	25-4S.-5W.
27	Ind., Spencer	Ohio Oil Co.	1 Holtzman	NE. SE. SE.	28-4S.-4W.
28	Ind., Perry	Ohio Oil Co.	1 W. Epple	NE. NE. NE.	8-5S.-3W.
29	Ind., Perry	Ohio Oil Co.	1 J. C. Harbaville	NE. SE. NW.	36-4S.-3W.
30	Ind., Perry	Outcrop at Branchville		SW.¼	13-4S.-2W.
31	Ind., Perry	Sun Oil Co.	1 Gibson	SE. SE.	17-4S.-1W.
32	Ind., Perry	Outcrop at Courcier Hill			10 & 11, 5S., 1W.
33	Ind., Crawford	Outcrop at Sulphur		SW.¼	31-3S.-1E.
34	Ind., Crawford	Outcrop at Leavenworth		E.½	6-4S.-2E.

LOCATIONS USED IN CROSS SECTIONS

Locations in Illinois (see tables 1, 2) and Indiana (tables 2–4) are described by the United States Land Office system of sections, townships, and ranges. Locations in Kentucky (see tables 3, 4) are given in the co-ordinate system for Kentucky originated by the Carter Oil Company about 1937 and now in common use by the oil industry. In this sytem, 5′ quadrangles are lettered in alphabetical order north from latitude 36°30′ and are numbered consecutively east from longitude 89°30′. Each 5′ quadrangle is thus indicated by a letter analogous to the township and a number analogous to the range of the standard system. Each of these quadrangles is subdivided into twenty-five 1′ rectangles which are called "sections" and approximate the mile-square Land Office sections in area but not in shape. The northeastern section in each quadrangle is numbered 1

and the northwestern 5. Six is immediately south of 5, and 10 is south of 1. The southeastern section is 21 and the southwestern is 25.

ACKNOWLEDGMENTS.—A report of this kind is possible only with the co-operation of numerous geologists and officials of oil companies, flourspar companies, and the several state agencies represented in the Eastern Interior region. It is probable that none of the correlations here presented are original; many have been worked out repeatedly and independently by different geologists and are part of the common unpublished knowledge of geologists active in the area. Unpublished reports of F. E. Tippie, formerly with the Illinois Geological Survey, have been used freely. The criticism and suggestions of L. E. Workman, A. H. Bell, H. B. Willman, and other members of the Survey have been very helpful.

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OSAGE-MERAMEC CONTACT[1]

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ABSTRACT

Evidence is advanced that indicates a major break within the Mississippian system of rocks at the end of the Osage epoch. A marked physical break is demonstrated in the upper Mississippi Valley area, the Batesville, Arkansas area, the northeastern Oklahoma area, the subsurface of Kansas, the southwestern New Mexico area, the northern Montana area, the Banff area in British Columbia, and the Wapiti Lake area in northern British Columbia. Widespread differences in the distribution of Osage and Meramec rocks are indicated, and, finally, attention is called to one of the most remarkable faunal breaks in the entire Paleozoic era.

INTRODUCTION

Serious divergence of opinion regarding recognition and usage of series and group units within the Mississippian system has existed among Mississippian stratigraphic workers for a considerable time. Evidence has accumulated that appears to indicate a major break at the end of the Osage epoch. This break appears to correspond with the major break recorded between rocks of Tournaisian and Viséan age in the European section. The evidence indicates the desirability of retaining the standard terms "Kinderhook," "Osage," "Meramec," and "Chester" and militates against any usage whereby Osage and Meramec rocks are classed together as a unit.

PREVIOUS WORK

The name "Osage" was proposed by H. S. Williams (1891, p. 169) for rocks of supposed Burlington and Keokuk age exposed along Osage River near Osceola, Missouri. It has since been determined (Kaiser, 1945, p. 34) that no rocks of Keokuk age are exposed in the area and that most of the Upper Burlington is missing. Therefore, it can be seen that the type section was unfortunately located.

The Osage group has since been expanded by various workers to include several early Osage formations. The New Providence formation of Kentucky and Tennessee (Moore, 1928, p. 167; Stockdale, 1939, p. 49), the Fern Glen formation of Missouri (Ulrich, 1911, pl. 29; S. Weller and St. Clair, 1928, p. 166; J. M. Weller and Sutton, 1940, p. 793; Cline, 1934, p. 1136; Stockdale, 1939, p. 41), the St. Joe formation of Arkansas and Oklahoma (Moore, 1928, p. 167; Laudon, 1939, p. 325), and the Lake Valley formation of New Mexico (Laudon and Bowsher, 1941, p. 2133) are all now classed as early Osage in age.

The only serious divergence of opinion with regard to the lower contact of the Osage is voiced by Branson (1938, p. 8), who believes that the Chouteau limestone and Fern Glen formation of Missouri are of the same age, and therefore Branson places the Fern Glen formation in the Kinderhook group.

The problem concerning the upper contact of the Osage group has been open to question for some time. The Warsaw formation (Hall, 1857) is considered by many workers (Van Tuyl, 1922, p. 184; Laudon, 1931, p. 341; Stockdale, 1939, p. 16) to be of Osage age and to contain a late Osage fauna. In general, many workers east of the Mississippi River have classed the Warsaw formation as basal

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Meramec in age (Ulrich, 1911, pl. 29; J. M. Weller and Sutton, 1940, p. 810).

The name "Meramec" was proposed by E. O. Ulrich (1904, p. 110) for the Warsaw, Spergen, and St. Louis formations. The Ste. Genevieve limestone, now commonly classed with the Meramec group, was then considered as basal Chester in age.

The name "Valmeyer" was suggested by Weller and Sutton for all rocks of Osage and Meramec age and was first used in classification by Moore (1933, p. 262).

Problems concerning the Osage-Meramec contact cannot be solved at the type sections of either the Osage or the Meramec series because both sections are incomplete. At the type section of the Osage, the Upper Burlington, Keokuk, Salem, and St. Louis formations are all missing. The Upper Burlington and Keokuk beds are exposed at other places in west-central Missouri, the Warsaw and Salem formations are not represented at all, and the St. Louis formation is known from only one small area. At the type section of the Meramec series, beds of Osage age are not exposed. In the vicinity, beds of Keokuk, Burlington, Reeds Spring, and Fern Glen age are exposed, but the Warsaw formation is not represented.

THE WARSAW PROBLEM

Because the Warsaw formation has been classified either with beds of Meramec age or with beds of Osage age, it appears logical to present the evidence that is available at the type section of the Warsaw formation in Soap Factory Hollow near Warsaw, Illinois. Re-examination of the type section and numerous other sections on both the Illinois and the Iowa sides of the Mississippi River has yielded considerable information.

At the type section, slightly over 118 feet of strata occur between the last crystalline crinoidal beds of the Keokuk formation and the contact of the St. Louis limestone. No beds of Salem age were recognized in this area. No evidence was found at the type section for separating some 10 feet of cross-bedded calcareous sandstone, that lies immediately beneath the St. Louis limestone in the area, from the Warsaw formation. This sandstone has been considered to represent the Salem formation (S. Weller, 1908, p. 163).

No evidence of disconformity was found between rocks of Keokuk age and the Warsaw beds at the type section or at several other sections studied in the area. The Keokuk beds become more shaly in the upper portion and grade insensibly up into the Warsaw formation. Several measurements from the top of the crystalline crinoidal Keokuk beds up to known horizons within the Warsaw were made in an attempt to demonstrate transgressive overlap against the Keokuk surface. In all cases the thickness was very constant, and no evidence of disconformity was noted.

No evidence of a physical break was found within the Warsaw formation. A study of various intervals within the Warsaw formation on several sections demonstrated no evidence of unconformity within the formation. Abundant faunas do appear quite suddenly in the middle part of the section, but in most cases the species are identical with forms that occur in the shaly beds in the upper portion of the Keokuk formation.

The contact between the Warsaw formation and the overlying St. Louis limestone is remarkably unconformable. Deep channeling and considerable relief can be demonstrated on the Warsaw surface within very short distances. True

conglomerates (not St. Louis brecciated limestone) are present in some of the deeper channels on the Warsaw surface. At several exposures large blocks of brown, upper Warsaw dolomite beds are re-worked into the basal St. Louis beds.

Because of the general confused state of the Warsaw problem we have deemed it wise to disregard completely all previously published lists of faunas. Accordingly, faunas were collected from both Warsaw and Keokuk formations in the type areas. Our new collections are not large, but the common forms of both formations are represented. Analysis of the Warsaw fauna indicates very close relationships with that of the underlying Keokuk formation. Thirty species of abundant Warsaw forms were identified, and twenty-seven of them were found in the underlying Keokuk rocks. The occurrence of *Metablastus wortheni*, *Dizygocrinus indianensis*, *Macrocrinus jucundus*, *Spirifer tenuicostatum*, *Cleiothyrindina obmaxima*, *Echinoconchus alternatus*, *Athyris lamellosa*, *Reticularia pseudolineata*, *Lioclema gracillamum*, *Hemitrypa proutana*, and *Bactropora simplex* in the Warsaw fauna indicates very strong affinities with the underlying Keokuk beds.

Comparison of the Warsaw fauna with twenty abundant species from the type area of the Salem formation shows almost no affinities at all. Only one species, *Pentremites conoideus*, was found in both faunas.

This observation contrasts sharply with general opinion regarding the relationships of the Warsaw-Salem faunas (J. M. Weller and Sutton, 1940, p. 808). Because of the relatively small portion of the Salem fauna that was used in our observations, it is entirely possible that we have arrived at an erroneous conclusion. Our Salem fauna consisted entirely of the diminutive forms from the oölite facies of the Salem formation, and because this is a facies fauna it may be entirely misleading. The writer has not had opportunity to study the field relationships of equivalent formations in southern Indiana.

It seems probable that the Warsaw beds exposed in the type area are the last deposits of the Osage seas. The calcareous facies of the Keokuk and older Osage formations in general become more clastic eastward toward the Appalachian Mountains (Stockdale, 1939, pp. 16, 18). It is normal that, as uplift progressed in eastern areas near the end of the Osage epoch, the clastic facies shifted farther to the west, away from the mountains that were forming. The Warsaw does resemble the clastic facies of the older Osage formations farther east and does not resemble typical Meramec rocks. The Salem limestone is considered in this paper as the base of the Meramec series in the upper Mississippi Valley area, but our evidence for placing it in the base of the Meramec is weak and inconclusive and needs further study. If the Salem limestone is a calcareous facies development within the Warsaw formation, as suggested by Weller and Sutton (1940, p. 803), this classification will need serious revision.

A spectacular unconformity, as well as distinctive faunal and lithologic breaks, marks the contact between Meramec and older Mississippian rocks in all areas in which the writer has had experience in western North America. A few areas have been chosen to illustrate this physical break.

BATESVILLE AREA, ARKANSAS

Confusion in the Batesville area (fig. 1) is due mainly to failure of workers to recognize different zones within the Osage section (Girty, 1915, p. 5). The

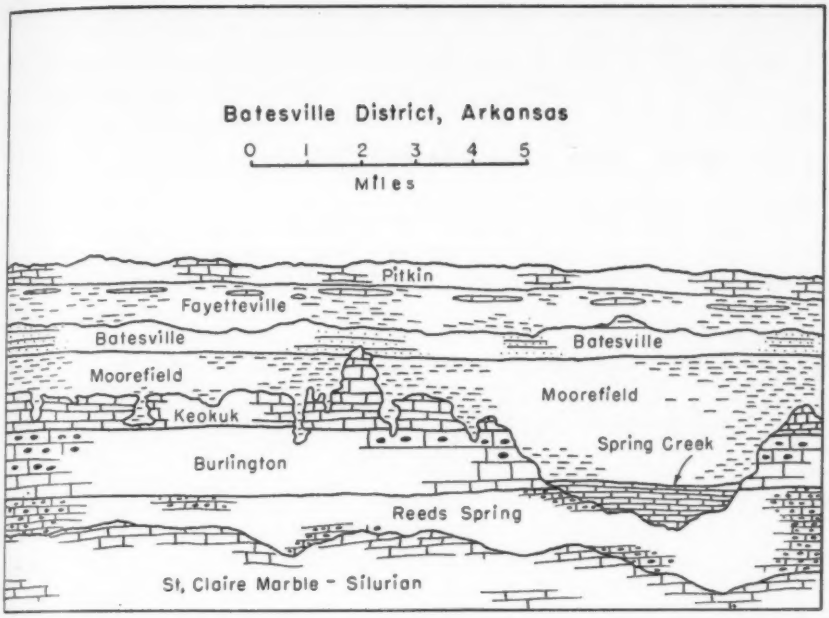


FIG. 1.—Diagrammatic sketch, showing the general stratigraphic relationships of Mississippian formations in the Batesville area, Arkansas.

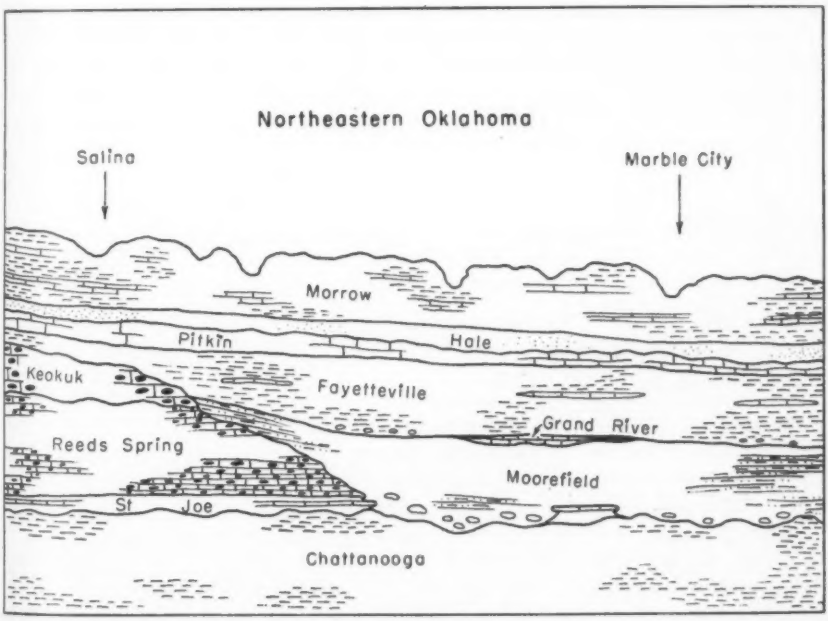


FIG. 2.—Diagrammatic sketch, showing the relationships of Osage rocks to the younger Mississippian rocks in northeastern Oklahoma.

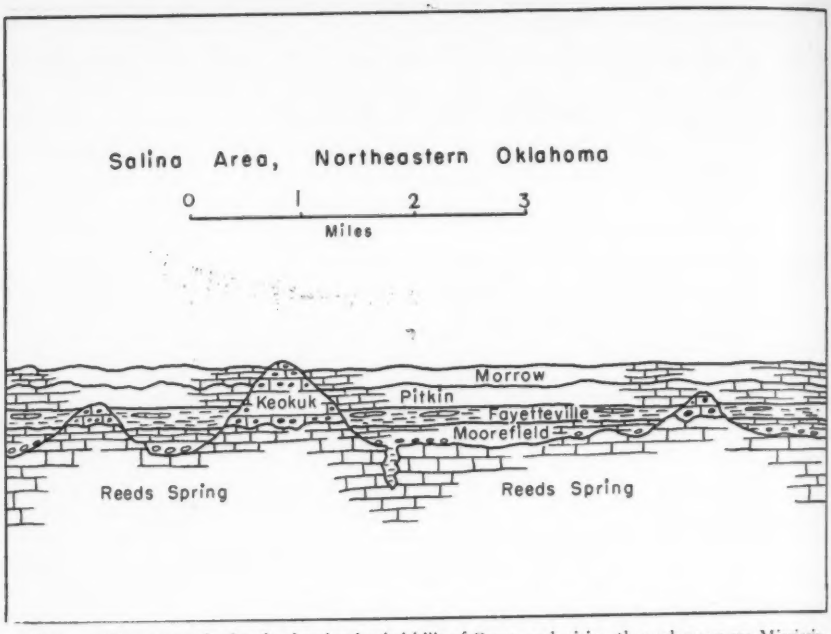


FIG. 3.—Diagrammatic sketch, showing buried hills of Osage rock rising through younger Mississippian strata in the Salina district, Oklahoma.

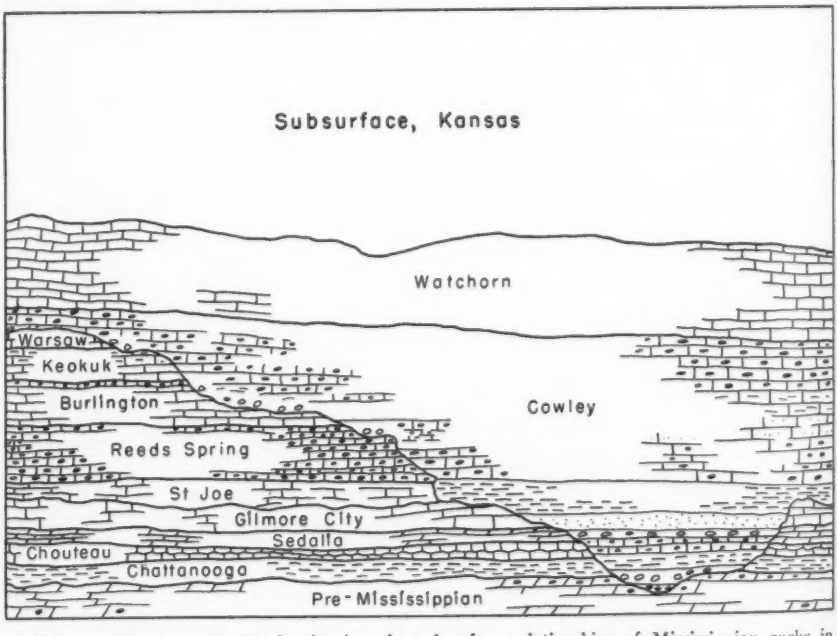


FIG. 4.—Diagrammatic sketch, showing the subsurface relationships of Mississippian rocks in Kansas.

St. Joe limestone is absent over most of the area, and the Reeds Spring cherty limestone rests on the eroded surface of the St. Claire limestone of Silurian age. Typical Burlington limestone is present, but apparently only the upper Burlington beds are represented. The Keokuk is represented by the typical southern and southwestern Ozark facies in which massive, gray, crinoidal, noncherty limestone beds are developed. It is possible that the upper portion of these limestone beds actually is a southwestward equivalent of the Warsaw formation, although what meager fauna is present belongs typically with the Keokuk.

The Moorefield and Batesville formations of early Meramec age are found in contact with beds of the Osage section ranging in age from Reeds Spring to late Keokuk within a few miles of Batesville. A veritable karst topography was developed on the Osage surface before the deposition of Meramec sediments. Deep sinkholes penetrate the Osage rocks and in some of the old quarries east of Batesville extend over half the quarry face. At Ruddells Mill, west of Batesville, the Spring Creek member of the Moorefield shale lies in contact with the Reeds Spring formation. The Spring Creek sediments were deposited only in the lowest erosional channels on the Osage surface, explaining its very local distribution in the area. The total relief on this surface is well over 150 feet within very short distances.

NORTHEASTERN OKLAHOMA AREA

The entire Osage section is truncated and overlapped by rocks of Meramec age from south to north in northeastern Oklahoma (fig. 2). First recognition of this truncation was presented by Cline (1934, p. 1157). Just north of Marble City the Moorefield formation is locally in contact with the Chattanooga shale and a conglomerate consisting of reworked Osage chert is present in the base of the Moorefield.

In the Salina district (fig. 3) in northeastern Oklahoma remnant hills of Reeds Spring and Keokuk chert extend through the thin northern edge of Moorefield, Chester, and Morrow formations. Some of these chert hills projected high enough to be overlapped by Cherokee sediments. They are rather conspicuous topographic features in the area, since the soft Cherokee sediments have been removed by erosion, exposing the Morrow surface.

SUBSURFACE RELATIONS IN KANSAS

The complex subsurface relationships of the Mississippian rocks in Kansas (fig. 4) have been studied in detail by Lee (1940, p. 66). Remarkable relief was developed on the Osage surface before the deposition of the Cowley sediments. The Cowley formation as defined by Lee is roughly equivalent to the Moorefield formation of the southern Ozarks region. In some places in western Kansas the Cowley formation rests directly on pre-Mississippian rocks.

NORTH-CENTRAL IOWA AREA

No Osage rocks are exposed in north-central Iowa, but the remarkably rough Kinderhook (Gilmore City) surface (fig. 5) is probably a result of post-Osage erosion. In the Gilmore City area remarkable sinkholes have been formed in the Gilmore City limestone (Laudon, 1933, p. 21). These sinkholes, although in most cases filled with sediments of St. Louis age, have been reopened by recent subsurface drainage channels, so that the farmers of the area now drain the surface water from their farms into them. In the quarries at Gilmore City considerable portions of the limestone have been

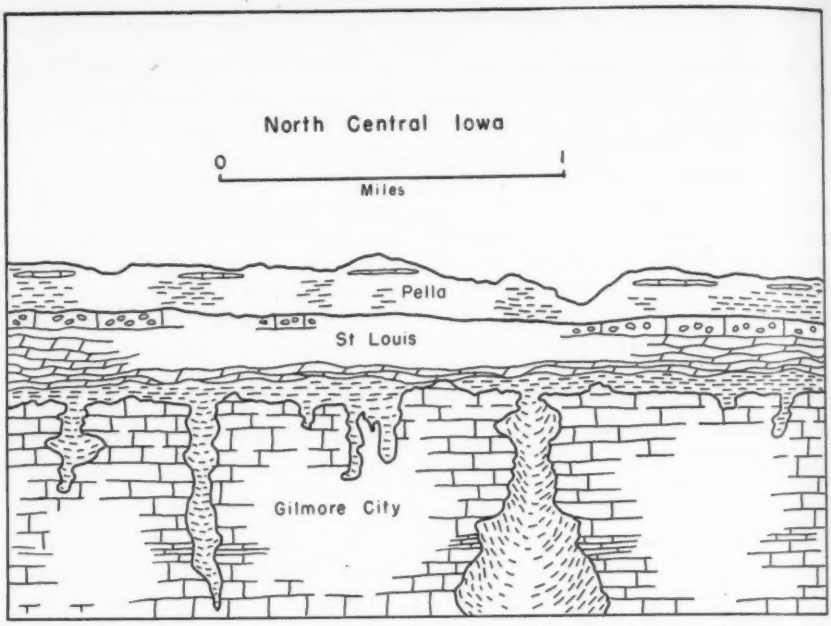


FIG. 5.—Diagrammatic sketch, showing the remarkable sinkholes developed on the Gilmore City limestone and later filled with sediments of St. Louis age.

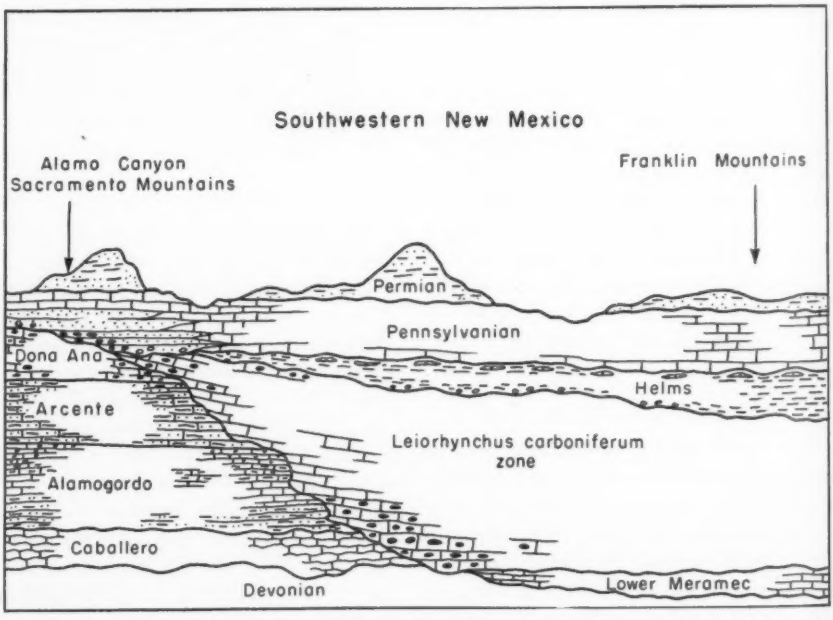


FIG. 6.—Diagrammatic sketch, showing the relationships of Kinderhook and Osage sediments to sediments of early Meramec age in southwestern New Mexico.

rendered almost unworkable because of channels filled with shales of St. Louis age.

SOUTHWESTERN NEW MEXICO AREA

The entire Kinderhook (Caballero) and Osage (Lake Valley) section is truncated southward in the Sacramento and San Andres Mountain areas in New Mexico and overlapped by sediments of early Meramec age (fig. 6). Siltstones carrying the *Leiorhynchus carboniferum* fauna, correlatives of the Moorefield formation of the Ozark area, are excellently exposed in the Hueco and Franklin mountain areas in New Mexico, where they rest on Devonian sediments. These early Meramec sediments transgressively overlap northward onto Kinderhook and Osage sediments in the Sacramento and San Andres Mountains and in their northernmost exposures may be seen in contact with the upper portion of the Lake Valley formation.

GALLATIN BASIN AREA, MONTANA

The Madison formation of Montana is usually divided into two members, Lodgepole below and Mission Canyon above (Sloss and Hamblin, 1942, p. 313). Recent work by Leonard (1946, p. 25) has demonstrated a widespread physical break within the Mission Canyon member. In the Gallatin Basin area (fig. 7) massive gray limestone beds carrying a *Lithostrotion* fauna rest with marked unconformity on the lower limestone beds of the Mission Canyon member. Faunas collected in the lower portion of the Mission Canyon indicate late Kinderhook age. No beds of Osage age were found in the area of the type section of the Madison limestone.

Deep sinkhole-like channels have been carved into the restricted Mission Canyon member, and re-worked materials of the underlying Mission Canyon limestone have been deposited in these channels. Excellent exposures showing these relationships have been developed in the north canyon wall of Yellowstone River, a few miles south of Livingston, Montana.

BANFF AREA, BRITISH COLUMBIA

In the Banff area in British Columbia confusion has arisen concerning the Mississippian stratigraphy of the area due mainly to erroneous identification of fossils and to the failure to recognize an unconformity that exists within the Rundle formation. The Mississippian section at Banff in British Columbia (fig. 8) consists of a shaly limestone series at the base that carries a Kinderhook fauna and is a direct correlative of the Lodgepole of Montana. This shaly series is overlain by the massive gray limestone beds of the Rundle formation. The massive limestone beds of the lower portion of the Rundle formation carry typical late Kinderhook faunas and correlate with the restricted Mission Canyon section in Montana.

The upper portion of the Rundle formation consists of massive gray, cherty limestone that carries a *Lithostrotion* fauna and is the equivalent, at least in part, of the St. Louis limestone of the Mississippi Valley. It is quite certain, however, that the Meramec portion of the Rundle formation represents considerably more time than does the St. Louis limestone of the Mississippi Valley.

The Meramec portion of the Rundle formation rests with marked unconformity on limestones of late Kinderhook age in the Banff area. The contact is everywhere overlain by a basal shaly zone that often carries phosphatic concreations and fish teeth. The change in

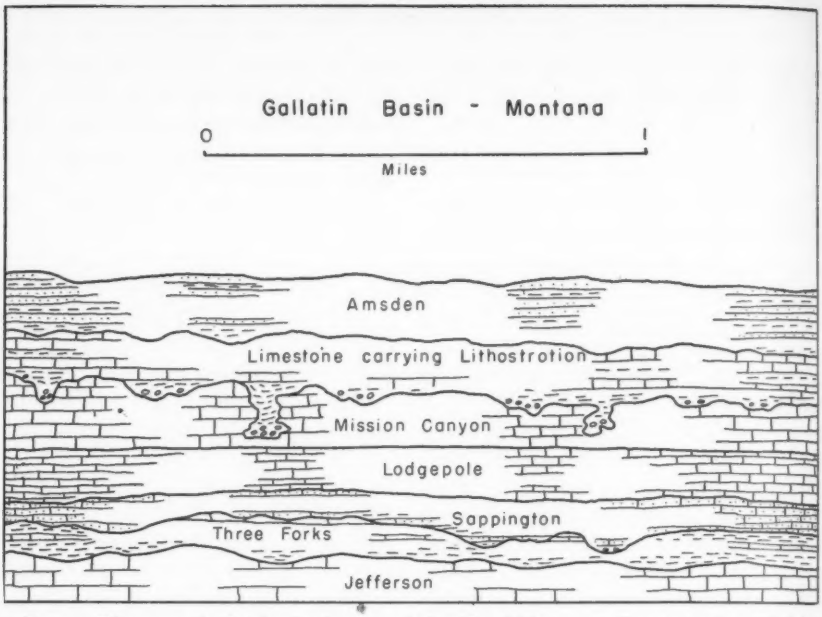


FIG. 7.—Diagrammatic sketch, showing the relationship of Meramec sediments to the underlying Kinderhook sediments in the Gallatin Basin area in northern Montana.

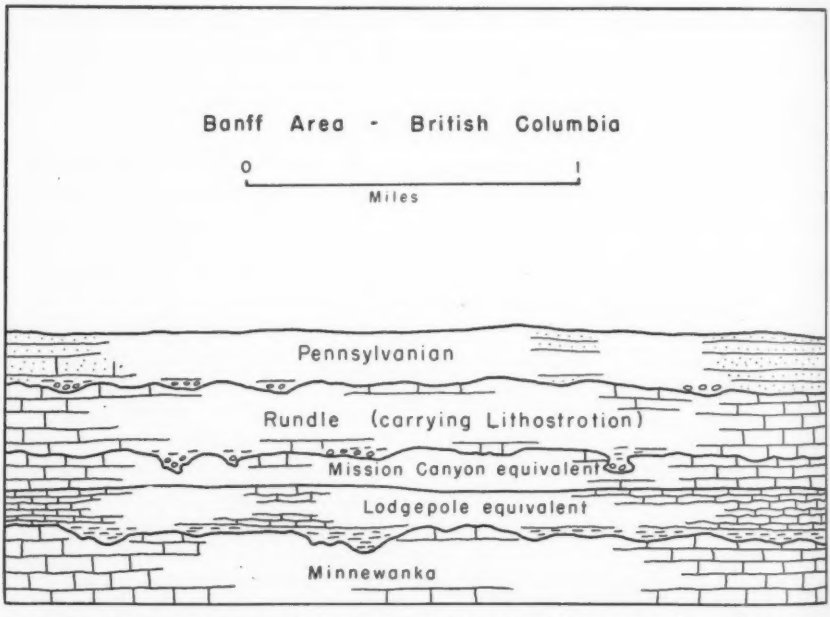


FIG. 8.—Diagrammatic sketch, showing the relationship of Kinderhook beds to the overlying Meramec beds in the Banff area, British Columbia.

lithology is abrupt, although both are limestones. Typical St. Louis lithology appears immediately above this contact. Sufficient work was not completed in the area to determine the amount of relief of the Kinderhook surface.

lain by rhythmic sequences of limestone beds similar in lithology and fauna to the Lodgepole formation of Montana. These rhythmic limestones are overlain by a thick accumulation of gray, massive limestone beds, approximately equiva-

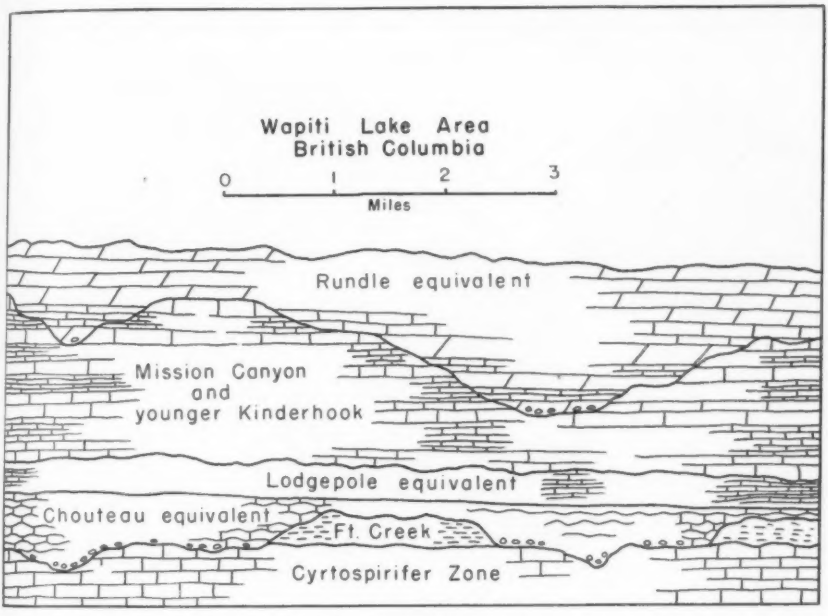


FIG. 9.—Diagrammatic sketch, showing the relationships of rocks of Meramec age to the underlying Kinderhook rocks in the Wapiti Lake area, British Columbia.

WAPITI LAKE AREA, BRITISH COLUMBIA

The Wapiti Lake area in British Columbia lies at the east edge of the Canadian Rocky Mountains, south of the Peace River, approximately 100 miles directly west of Grande Prairie, Alberta. Mississippian rocks (fig. 9) are unusually well displayed in the area and are very fossiliferous, making close correlation possible.

The basal beds consist of nodular, gray limestone carrying an abundant fauna, remarkably similar to that of the Chouteau formation of the Mississippi Valley area. The nodular beds are overlent in age to the lower portion of the Mission Canyon formation of Montana. No rocks of Osage age were recognized in the area. The Kinderhook rocks are overlain by brown, sugary dolomites and gray, cherty limestone beds that carry a rich *Lithostrotion* fauna. These beds are similar to some in the upper portion of the Rundle formation of the Banff area. The beds of Meramec age rest on rocks of late Kinderhook age with marked unconformity. Within a distance of less than 5 miles they were found to overlap against considerably more than 500 feet of Kinderhook strata.

DISTRIBUTION OF MERAMEC VERSUS OSAGE ROCKS

If the distribution of Osage rocks is compared to the distribution of Meramec rocks, an important break between the two series is suggested.

Osage rocks have a rather local distribution in comparison with Meramec rocks (fig. 10). Osage rocks are known today from the Appalachian slope region, the Mississippi Valley, and Mid-Continent regions. In the west they are confined to New Mexico, to parts of Arizona, and to local exposures in southern Nevada. They are entirely missing in the northern Rockies and in the Canadian Rockies.

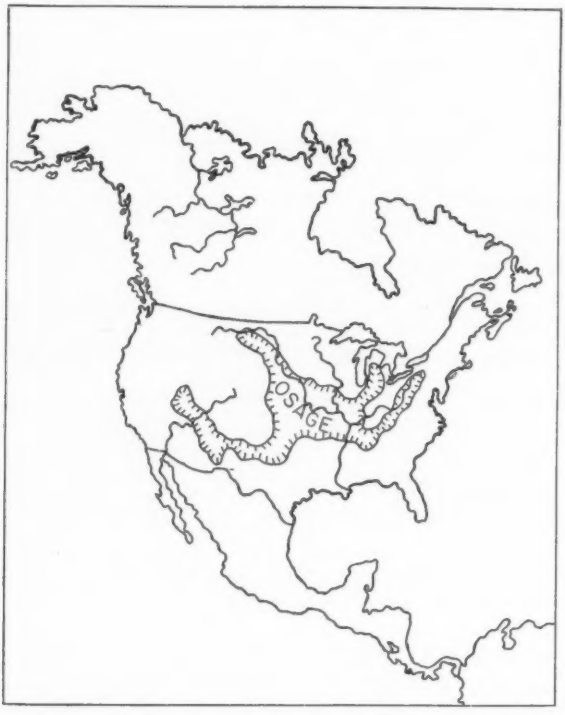


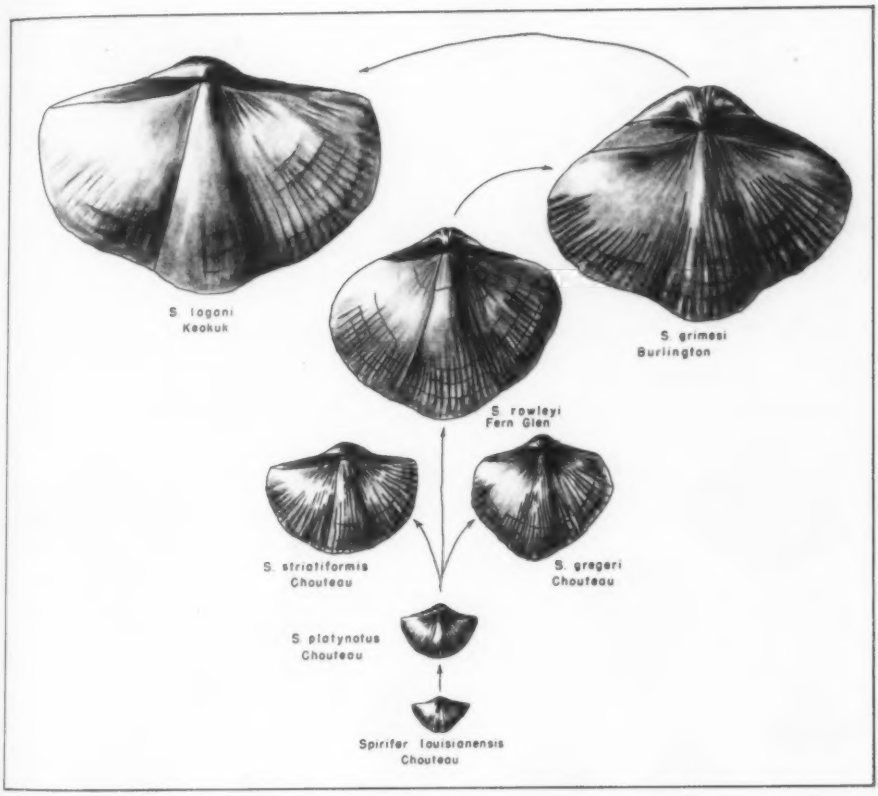
FIG. 10.—Map showing the general distribution of Osage rocks in North America

In contrast to this, rocks of Meramec age widely overlap onto Kinderhook and older surfaces (fig. 11). In western United States the distribution of Meramec, however, extends into the northern Rockies, the Canadian Rockies, and Alaska.

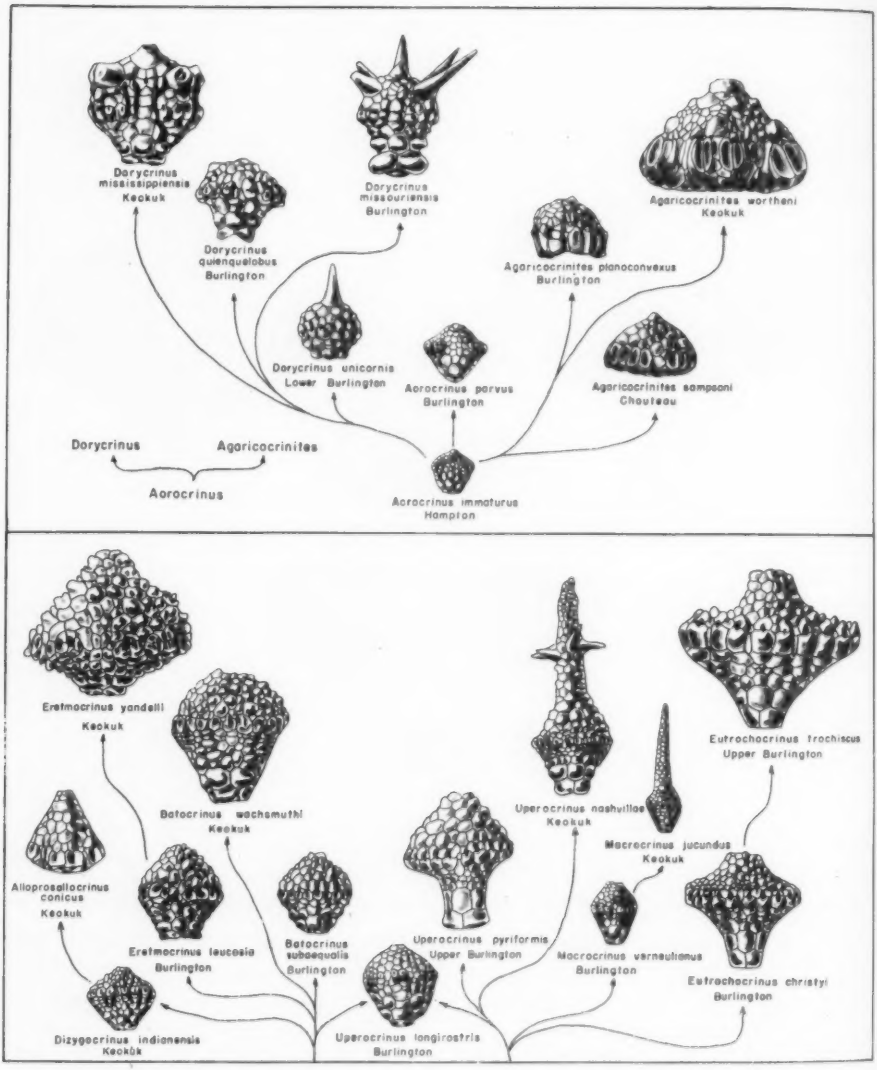
PALEONTOLOGY

Careful analysis of the ranges of fossils within Mississippian rocks reveals one of the most remarkable faunal breaks in the whole Paleozoic sequence at the end of the Osage series. Kinderhook and Osage species appear to be closely related and often exhibit very complete evolutionary series. Meramec and Chester species show very little relationship to those of the Osage and, in general, are much more closely allied with the younger Pennsylvanian species than with the older Mississippian forms.

Most remarkable is the almost com-

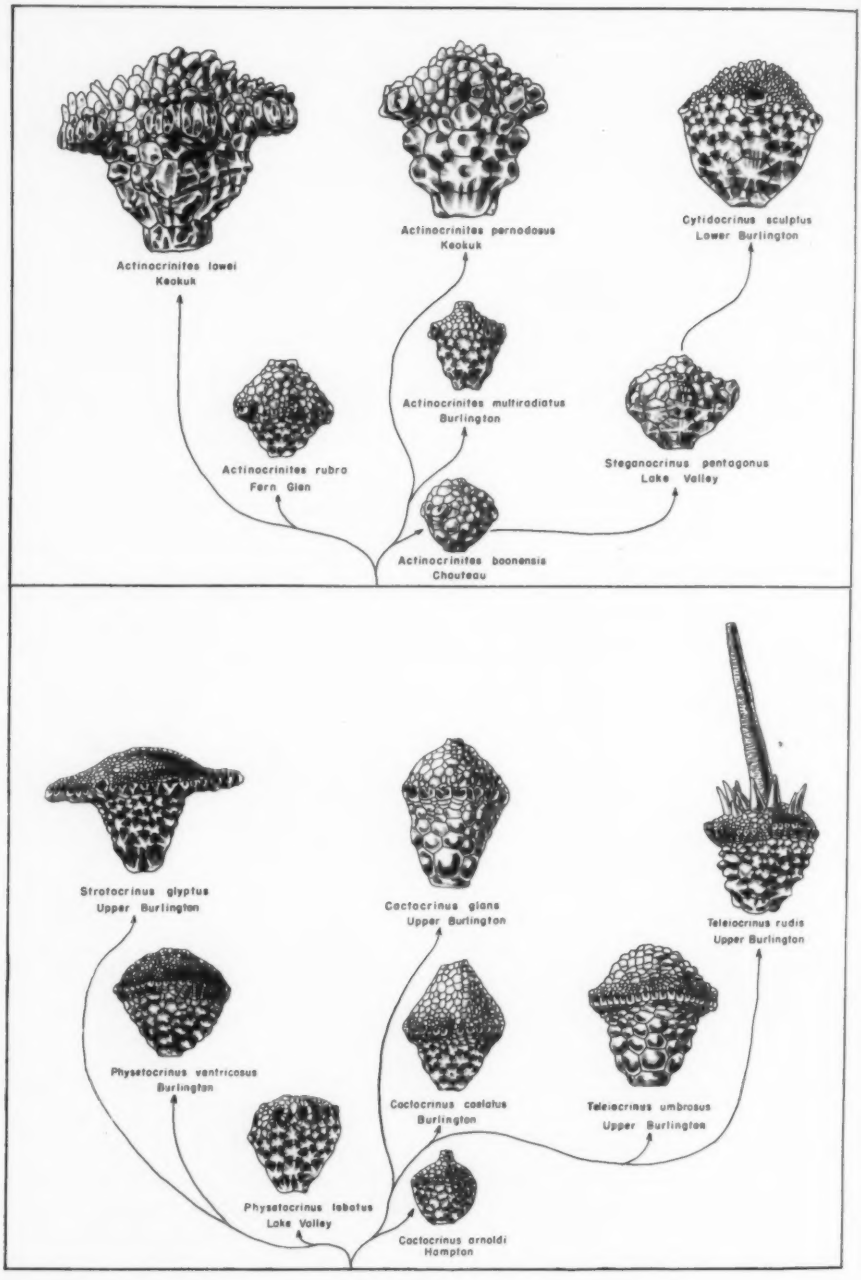


Evolution chart, showing the Kinderhook and Osage species of the genus *Spirifer*. None of these species occur in Meramec or Chester rocks.



Upper, Evolution chart, showing Kinderhook and Osage species in the family Desmidocrinidae. None of these genera or species occur in Meramec or Chester rocks.

Lower, Evolution chart, showing Kinderhook and Osage species in the family Batocrinidae. None of these genera or species occur in Meramec or Chester rocks.


Actinocrinites lowei
Keokuk
Actinocrinites pernodosus
Keokuk
Cytidocrinus sculptus
Lower Burlington
Actinocrinites multiradiatus
Burlington
Actinocrinites rubra
Fern Glen
Steganocrinus pentagonus
Lake Valley
Actinocrinites boonensis
Chouteau
Strotocrinus glyptus
Upper Burlington
Cactocrinus glans
Upper Burlington
Teleiocrinus rudis
Upper Burlington
Physetocrinus ventricosus
Burlington
Cactocrinus caelatus
Burlington
Teleiocrinus umbrosus
Upper Burlington
Physetocrinus labatus
Lake Valley
Cactocrinus arnoldi
Hampton

plete annihilation of the highly specialized Osage fauna. Of the 54 most commonly occurring Kinderhook and Osage brachiopod genera, 26 are limited to the Kinderhook and Osage (pl. 1). Only 1 genus is limited to the Meramec and Chester. Only 1 known species (*Linoproductus ovatus*) crosses the Osage-Meramec line. The most outstanding faunal change is the remarkable disappearance of the camerate crinoids (fig. 12). Of 321 abundant Mississippian camerate crinoid species, 298 are restricted to Kinderhook and Osage rocks, and only 23 occur in rocks of Meramec and Chester age. Of 20 species in the family Rhodocrinitidae, none crosses the Osage-Meramec line. Of 127 species falling in the Desmidocrinidae and Bactocrinidae, none crosses the Osage-Meramec line (pl. 2). Of 66 commonly occurring species in the Actinocrinitidae (pl. 3), none crosses the Osage-Meramec line. Of 58 species in the Platycrinitidae, 57 fail to cross the Osage-Meramec line, and only 1 known species is restricted to the Upper Mississippian rocks. Of the 46 commonly occurring species of the Dicho-

FIG. 11.—Map showing the general distribution of Meramec rocks in North America

PLATE 3

Upper, evolution chart showing Kinderhook and Osage species of *Actinocrinites*, *Steganocrinus*, and *Cytidocrinus*. None of these genera or species occur in Meramec or Chester rocks.

Lower, Evolution chart showing Kinderhook and Osage species of *Cactocrinus*, *Physetocrinus*, *Strotocrinus*, and *Teleiocrinus*. None of these genera and species occur in Meramec or Chester rocks.

crinidae, 19 are found in the Upper Mississippian rocks, but all are easily distinguishable from Kinderhook and Osage forms. No known species of *Dichocrinus* crosses the Osage-Meramec line.

Of 57 commonly occurring Mississippian species of flexible crinoids, only 7 are known from Meramec and Chester rocks. None of the species in the Lecanocrinidae and Sagenocrinidae and only 1 of the species in the Ichthyocrinidae occur in the Upper Mississippian rocks. Six of the 28 species of the Taxocrinidae are found in the Upper Mississippian rocks, but no species crosses the line. Of 37 commonly occurring Mississippian inadunate crinoid genera, 23 do not cross the Osage-Meramec line. Four genera—*Graphiocrinus*, *Linocrinus*, *Culmicrinus*, and *Cyathocrinus*—cross the Osage-Meramec line, but no species are known to do so. Two genera of inadunate crinoids start in the Meramec, and 8 start in the Chester.

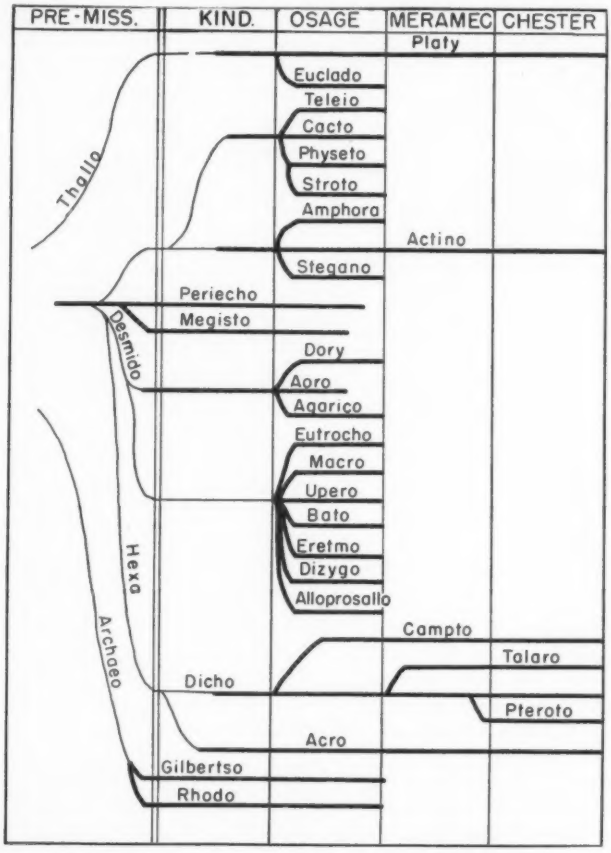


FIG. 12.—Chart showing the range of Mississippian camerate crinoid genera

TOURNAISIAN-VISÉAN BREAK IN THE BRITISH ISLES

Throughout most of the more definitely offshore areas of Mississippian rocks, namely, the Mississippi Valley, the Mid-

Continent, and western North America, the lower Kinderhook beds consist of clastic shales, silts, and calcareous mudstones with intercalated nodular limestone beds. Beds similar in lithology and remarkably similar in fauna occupy the more definitely marine portion of the Tournaisian section in the British Isles. The zones of Km, K_1, and K_2 correlate, in general, with our Chattanooga, Saverton, Louisiana, Hannibal, Chouteau, Sedalia, Caballero, Lodgepole, and upper Banff limestone sections. Exact correlations cannot be made, but faunas and lithology correspond remarkably closely.

Massive gray limestone beds, many of them oölitic, interbedded with darker, more clastic, shaly limestone beds usually follow next in stratigraphic order in North America. These beds, except for the Gilmore City limestone of Iowa, are not present in the upper Mississippi Valley province or in the Mid-Continent region. However, they are excellently displayed throughout most of western North America. The massive gray limestone beds of the Leadville limestone of Colorado, most of the Pahasapa limestone of the Black Hills, the basal portion of the Rundle limestone in southern British Columbia, and a thick series of limestone beds in the Wapiti Lake area in northern British Columbia belong to this period of deposition. In western North America these beds are characterized by the abundance of Zaphrentid corals and late Kinderhook crinoid faunas. The massive, gray, crinoidal limestone beds of the Z_1 and Z_2 zones of the British Isles correlate, in general, with this portion of the American section. The abundant occurrence of Zaphrentid corals and a remarkably similar brachiopod fauna in the British section support this correlation.

The deposition of the gray, massive limestone beds in the late Kinderhook marks one of the maximum floods of Mississippian seas in North America. Immediately following this flood, the seas began to withdraw rapidly from North America, resulting in considerably less widespread deposition of Osage sediments. Contrary to popular opinion, no beds of Osage age are known in British Columbia, northern Montana, the Black Hills, and Colorado. Beds of Osage age are limited to the Mississippi, Ohio, and Tennessee drainage areas, the Mid-Continent region, and local parts of New Mexico, Arizona, and Nevada. The Osage beds, in general, represent the final deposition before the important Osage-Meramec break. Such highly specialized evolutionary types as characterize the late Osage beds commonly occur during periods of rapid environmental change. *Caninia* first occurs in abundance in the American section in beds of early Osage age. The massive crinoidal limestone beds of the C_1 zone of the British section correlate very closely with the Osage beds of America. The first abundant occurrence of *Caninia* occurs in these beds in the British section, and, as in America, highly developed crinoidal bioherms are developed in the Coplow Knoll area. Such common Osage crinoid genera as *Actinocrinites* and *Gilbertsocrinus* occur abundantly in the Coplow Knoll fauna. These genera do not range beyond the Osage in North America.

If we neglect the highly problematical Warsaw and Salem formations of the Mississippi Valley area, the next widespread Mississippian deposition in North America is characterized by widespread accumulation of highly clastic siltstones and shales that are occasionally somewhat calcareous. All over North America they are marked by the occurrence of the *Leiorhynchus carboniferum* fauna. These beds are represented by the Moorefield and Batesville formations of the Ozark

province, the Cowley formation of the subsurface of Kansas, the Sycamore limestone of the Arbuckle Mountains of Oklahoma, the lower portion of the Helms formation of New Mexico, and the thick accumulations of sediments in northern British Columbia, in Yukon, and in the Calico Bluff area in Alaska. At no known place in North America are beds of Moorefield age actually in contact with younger beds of Meramec age on the surface, unless it is in the northern portion of Alaska in the Cape Lisburne area. Indicated stratigraphic position of the Moorefield formation and its equivalents has been determined entirely on the basis of the stage of evolution of the fauna, and the evidence is not conclusive. It is entirely possible that the fauna is of late Meramec age. The zone of C_2 in the British section corresponds in lithology and stratigraphic position with that of the *L. carboniferum* beds of North America. However, the fauna of the C_2 zone has very little in common with that of the *L. carboniferum* beds of North America. The zone of C_2 in the British Isles lies with marked unconformity on underlying strata and carries *Lithostrotion* and typical Meramec fossils. The Tournaisian-Viséan break is often placed between the zones of C_1 and C_2 by British workers. Thus it can be seen that the Tournaisian-Viséan break in the Lower Carboniferous section of the British Isles is directly comparable to the Osage-Meramec break in North America.

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PROBLEM OF THE "MAYES" IN OKLAHOMA[1]

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ABSTRACT

The Mayes formation consists of those beds of Mississippian age underlain by the Boone (Osagian) and overlain by the Fayetteville (Chesterian) in the outcrops in Mayes County, Oklahoma, and is generally considered to be equivalent in age to the Moorefield and Batesville formations. The name was proposed by L. C. Snider in 1915 and correlated as lower Chester. In 1927, George S. Buchanan applied the name to the dark, argillaceous, silty limestone of the subsurface Mississippian and correlated the lower part at least with the Meramec series. In 1930, Ira H. Cram introduced convincing evidence that the subsurface "Mayes" was a facies of the Boone and was therefore of Osage age. Since that time the name has persisted, as has the confusion and controversy. Much new evidence, by deep drilling in western and northwestern Oklahoma, supports the general opinion of subsurface geologists that the "Mayes" of the subsurface is of Osage age and is not a correlative of the Mayes formation of the outcrop section in northeastern Oklahoma.

INTRODUCTION

"Mayes" is the name commonly applied to the clastic limestone of the subsurface Mississippian found between the Arbuckle Mountains and the Mississippian outcrops of northeastern Oklahoma. In the greater part of this area it overlies the Woodford shale of Kinderhook age and is overlain by the Mississippian black shales, herein referred to as "Caney."

A number of papers have been published in which the "Mayes" has been correlated with strata in the classic Mississippi River section. In most published reports it is classified as Meramecian. In one early publication correlation with the Osagian is suggested.

Subsurface geologists, who have traced the "Mayes" throughout the area in which it occurs, almost unanimously correlate it with the Osage series. According to this view, the "Mayes" is a remarkable change in facies, which is not uncommon in Mississippian rocks of Osage age.

The subsurface "Mayes" is correlated with the formation of that name in the outcrop section of northeastern Oklahoma by the authors of several published reports. These efforts to establish the age of the "Mayes" as Meramecian have not been convincing to the subsurface geologist acquainted with the problem. On the other hand, the only published assertion of Osage age of the "Mayes" has not been generally accepted.

Another approach to the age problem is provided by the subsurface section of the Mississippian found in the Anadarko Basin of southwestern Kansas and northwestern Oklahoma, where the thickest section of Mississippian deposits in this province is found. The correlation of these beds indicates the Osage age of the subsurface "Mayes" and precludes its correlation with the outcrop formation of that name.

The subdivisions of the Mississippian section other than those considered to be Osagian, are discussed in this paper only in so far as they pertain and contribute to the solution of the "Mayes" problem.

EARLIER WORK ON MISSISSIPPIAN STRATIGRAPHY OF OKLAHOMA

The outcrops of the Mississippian strata in northeastern Oklahoma have been studied repeatedly since the turn of the century. Equivalents of the four major subdivisions of the classic Mississippi River section (table 1) were recognized early in the unraveling of the stratigraphy of this area. Later detailed work led to the naming of the individual members, formations, and groups and their probable correlation with the out-

[1] Manuscript received December 22, 1947.

crops of the adjacent southwest Ozark region of southwestern Missouri and northwestern Arkansas.

Some of the early work was done by L. C. Snider (1915), who proposed the name Mayes for the basal formation of the Chester series in Mayes County, Oklahoma. The formation consists of the beds overlying the Boone unconformably and underlying the black shale of the Fayetteville formation. These beds, according to Snider's interpretation, were definitely the age equivalent of the Moorefield shale and Batesville sandstone of Arkansas. The Moorefield has since been definitely correlated as Meramecian by Mackenzie Gordon, Jr. (1944).

The Meramec age of the lower part of Snider's Mayes formation was recognized by George S. Buchanan (1927), who applied the name to the black, argillaceous Mississippian lime section of the subsurface, found in the lower part of the Caney shale. He extended the correlation south and west of the outcrop area to the Arbuckle Mountain region and north to the Kansas line. Buchanan apparently based his correlations, first, on the similarity of the lithology of the subsurface Mississippian rocks and the Mayes formation of Snider and, second, on the correlation of Aurin, Clark, and Trager (1921), which indicated that the black lime of the subsurface was younger in age than the Boone and that the Boone was removed by erosion and was missing west of the outcrop area.

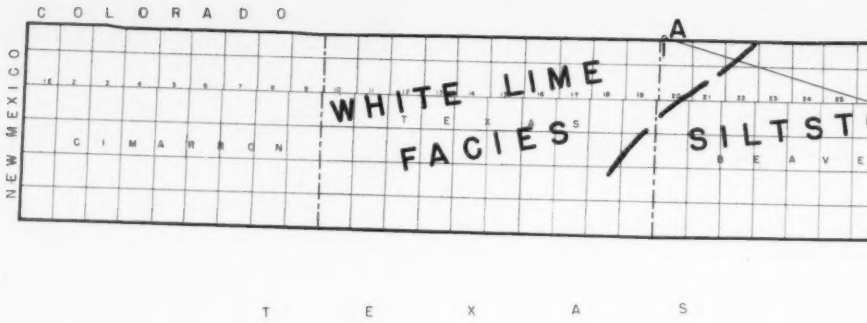
TABLE 1

	Mississippi Valley	Northeastern Oklahoma		South-central Oklahoma	Ouachitas
CHESTER		Pitkin			Basal Stanley?
		Fayetteville			
MERAMEC	Ste. Genevieve	Batesville	Mayes of Snider	Caney	Absent
	St. Louis	Ruddell			
	Salem (Spergen)	Moorefield			
	Warsaw				
OSAGE	Keokuk	Boone	"Mayes" of subsurface	Sycamore	Absent
	Burlington				
	Fern Glen	St. Joe		Welden	
KINDERHOOK	Chattanooga	Chattanooga		Woodford	Upper Arkansas novaculite

A few years later Ira H. Cram (1930) questioned the validity of Buchanan's correlation and offered some convincing arguments supporting his contention that the "Mayes" of the subsurface probably represented a remarkable change in facies of the Osage rocks from the white cherty limestones of the typical Keokuk-Burlington beds.

CORRELATION AND THICKNESS OF MISSISSIPPIAN SUBSURFACE STRATA IN NORTHWESTERN ANADARKO BASIN

The four major subdivisions of the Mississippian are represented in the

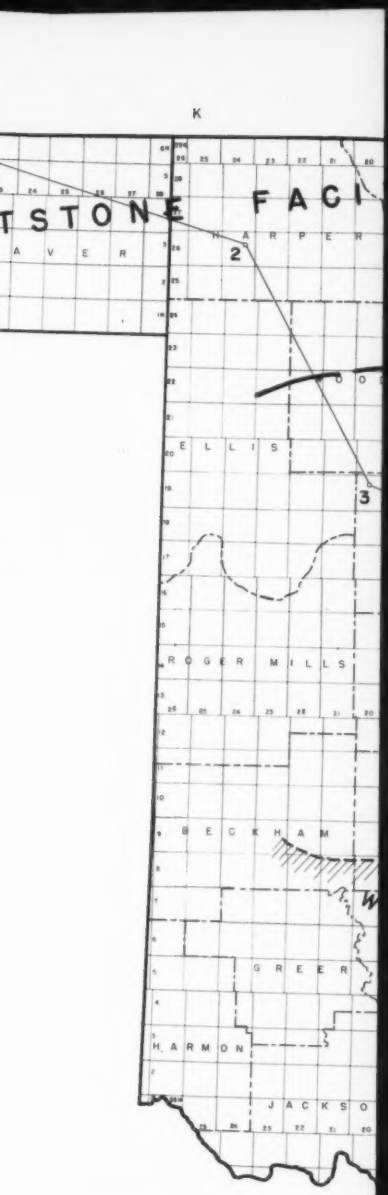


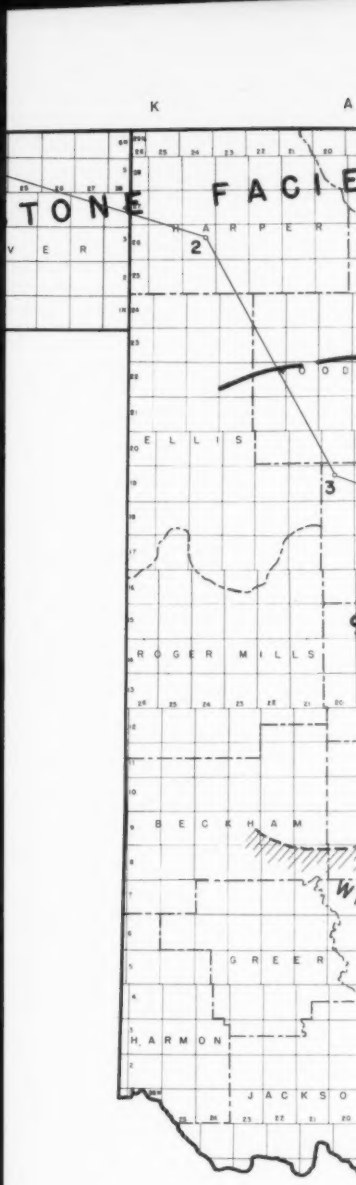
STATE OF OKLAHOMA

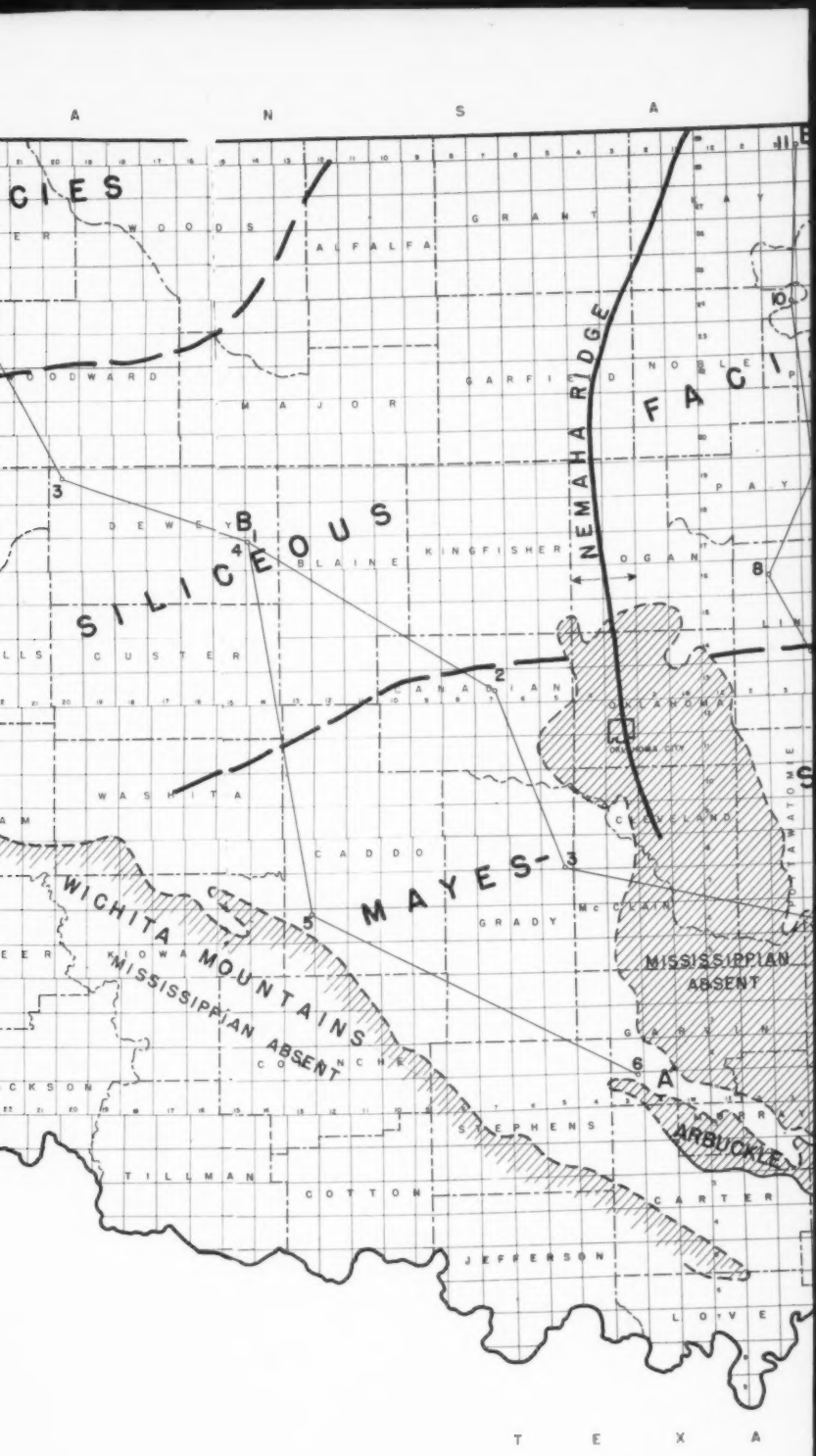
AREAL DISTRIBUTION OF DIFFERENT OSAGE FACIES

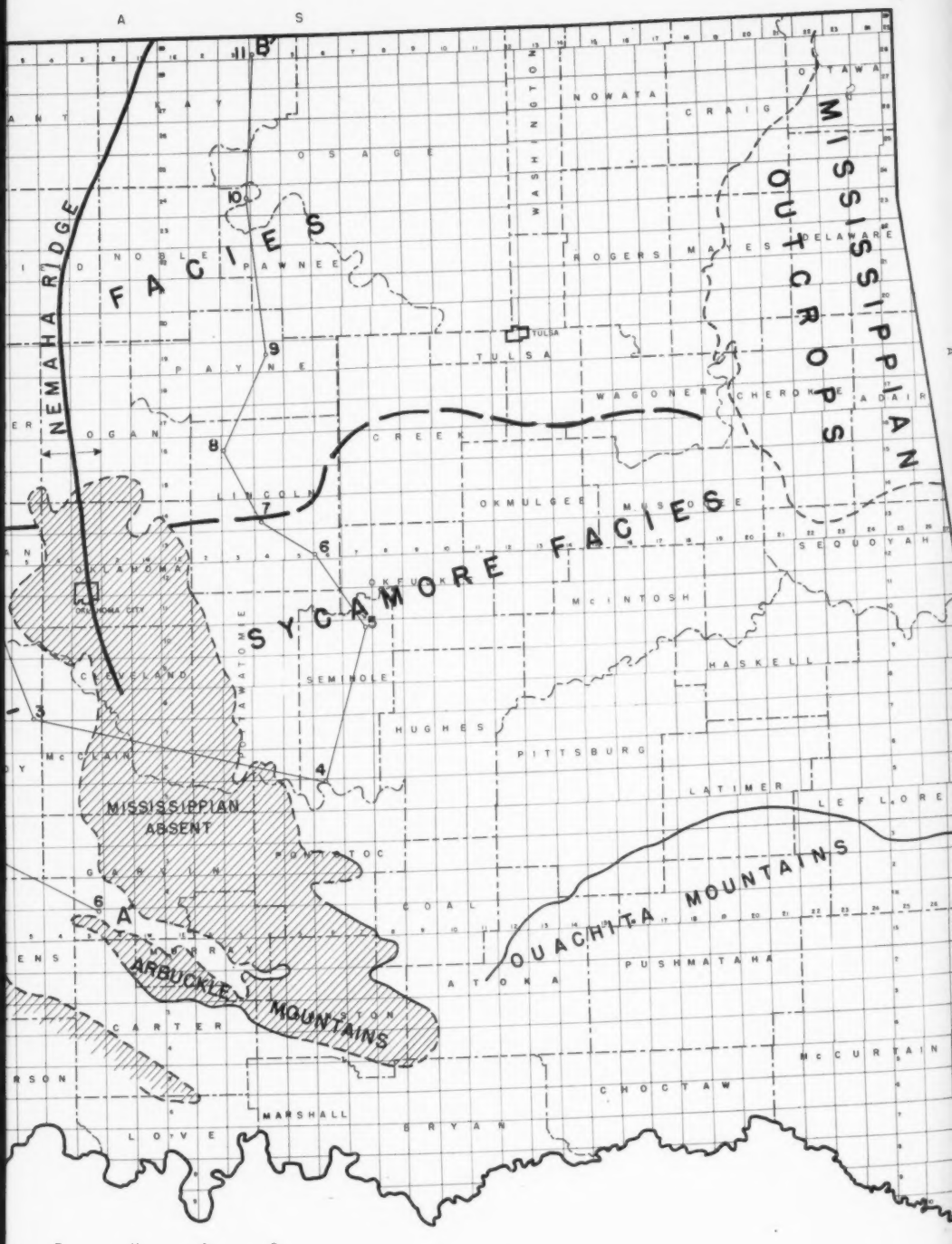
ERWIN L. SELK

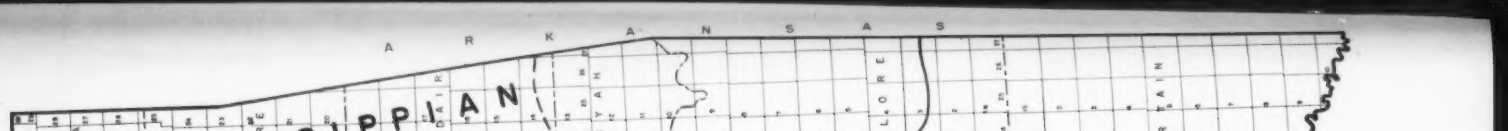
1947


K
FACI
HARPER
2
ELLIS
3
ROGER MILLS
BECKHAM
GREER
HARMON
JACKSO


K
A
TONE
FACIE
V E R
H A R P E R
2
O O D
E L L I S
3
R O G E R M I L L S
B E C K H A M
G R E E R
H A R M O N
J A C K S O


A N S A
CIES
WOODS
ALFALFA
GRANT
WOODWARD
MAJOR
GARFIELD
NOBLE
NEMAHA RIDGE
FACI
PAY
DEWEY
BLAINE
KINGFISHER
OGAN
SILICEOUS
CUSTER
ANADARKO
OKLAHOMA
OKLAHOMA CITY
WASHITA
CLEVELAND
POTTAWATOMIE
CADDO
MAYES
GRADY
MC CLAIN
WICHITA MOUNTAINS
KIOWA
COMANCHE
MISSISSIPPIAN ABSENT
MISSISSIPPIAN ABSENT
GARVIN
STEPHENS
ARBUCKLE
TILLMAN
COTTON
CARTER
JEFFERSON
LOVE
TEXA


A
S
B'
NEMAHA RIDGE
FACIES
MISSISSIPPIAN
OUTCROPS
SYCAMORE FACIES
MISSISSIPPIAN
ABSENT
ARBUCKLE MOUNTAINS
OUACHITA MOUNTAINS
OKLAHOMA CITY
TULSA
OSAGE
NOWATA
CRAIG
OTTAWA
WASHINGTON
PAWNEE
ROGERS
MAYES
DELAWARE
PAYNE
CREEK
WAGONER
CHEROKEE
ADAIR
LINCOLN
OKMULGEE
MUSKOGEE
SEQUOYAH
OKLAHOMA
OKFUSKEE
MCINTOSH
POTTAWATOMIE
CLEVELAND
SEMINOLE
HASKELL
HUGHES
PITTSBURG
MCCLAIN
LATIMER
LEFLORE
GARVIN
COAL
ATOKA
PUSHMATAHA
CARTER
JOHNSTON
MCCURTAIN
CHOCTAW
MARSHALL
BRYAN
LOVE
E X A S


ARKANSAS
MISSISSIPPI

Anadarko Basin and here attain their maximum thickness for this area.

Beds of Kinderhook age—the Woodford shale of this province—thin westward and pinch out entirely in the extreme northwestern part of the state, where the overlying Osage rocks rest upon Ordovician. The Woodford shale ranges in thickness from 0 to more than 500 feet.

Beds of Osage age have the lithologic characteristics of the Fern Glen formation in the lower part, and several facies of undifferentiated Burlington-Keokuk strata in the upper part. Their thickness varies from about 300 to 770 feet, except in areas of pre-Pennsylvanian truncation and along the Wichita Mountain front, where thicknesses in excess of 1,000 feet have been penetrated.

It is this series of beds which in Oklahoma has been correlated in various ways with the major subdivisions of the Mississippian and so engendered the existing confusion and controversy. The different facies of these strata, one of which is the "Mayes," will be discussed later in this paper.

The lithologic sequence of the beds in the Meramec series from the basal Warsaw formation up through the Ste. Genevieve formation is remarkably like the equivalents of the classic section in the subsurface of southwestern Illinois. This parallelism is so striking that the terminology of the Meramec formations in the classic section can be applied to these subsurface strata with assurance. The maximum thickness of these beds so far revealed in the subsurface is found in Beaver County, Oklahoma, where they are approximately 800 feet thick. These beds thin to the east. Because the section decreases from 600 feet to less than 100 feet across Dewey County, a pronounced pre-Chester unconformity is indicated.

The Chester overlies the Meramec, and its lithology is similar to that shown in the Illinois Basin section, with one disappointing exception—the well-defined sandstones of the type section have not been noted. Persistent fine-grained sandstones, however, occur in the lower part and are present higher in the section in those areas where the thickest Chester is found. Some of the limestone beds are similar to those of the Pitkin of the northeastern outcrops, but the black shales associated with the Pitkin occur only where the Chester changes facies along the north side of the Wichita Mountain front. Here it is approximately 2,400 feet thick, which is probably exaggerated because of steeply dipping beds, and overlies the Caney shales of Mississippian age.

The Chester age of the strata has been definitely established in southwestern Kansas from a study of the fauna obtained from numerous cores from exploratory wells. This determination was made by M. K. Elias[2] and as yet has not been published.

FACIES AND LITHOLOGY OF THE OSAGE

There are four distinctive facies (fig. 1) of the Osage encountered in the subsurface of Oklahoma which in this paper are referred to as (1) "White Lime" facies, (2) "Siltstone" facies, (3) "Siliceous" facies, and (4) "Mayes-Sycamore" facies. These facies are most marked in the Keokuk-Burlington portion of the Osage series. The Fern Glen formation, where present, commonly consists of characteristic gray-green shale and buff, dense limestone, in descending order, and varies in thickness from a few feet to as much as 100 feet.

The "White Lime" facies consists of white to light-gray cherty limestone, commonly coarsely crystalline and cri-

[2] Personal correspondence.

noidal and dolomitic in many places. The character of this facies strongly suggests a Keokuk-Burlington age, and it undoubtedly continues northward throughout western Kansas, where it is classified as upper Osage. Its occurrence in northwestern Oklahoma is probably limited to a very small area in the western part of the Oklahoma panhandle. This facies changes rather abruptly from northwest to southeast to the "Siltstone" facies.

The "Siltstone" facies is predominately a gray to dark-brown calcareous or dolomitic siltstone, varying in chert content. Commonly lenses of light-colored cherty dolomitic limestone, which are characteristic of the Keokuk-Burlington beds, occur within this mass. The siltstones become increasingly shaly and grade downward into a gray-green indurated shale with dense gray-buff limestones in the basal part. These lower strata are characteristic of Fern Glen. As one approaches the southeasterly limits of this facies, a transition into the "Siliceous" facies becomes evident.

The "Siliceous" facies consists of gray, brown, and black microcrystalline limestones. These beds are, for the most part, siliceous and cherty and occupy a broad belt north and west of the "Mayes-Sycamore" facies. Transitional interfingering of these two facies is evident east of the Nemaha Ridge, where there is an abundance of subsurface data (cross-section *BB'*).

The "Mayes-Sycamore" facies varies from the black to brown, micaceous, silty, and shaly limestone of the "Mayes" to the gray and tan speckled, granular, silty limestone of the Sycamore. A distinct brown to black glauconitic zone occurs at the base in most places. This gauconite bed is continuous and is also present at the base of the "Siliceous" facies. The "Mayes" and Sycamore are unquestionably correlative. Both occupy a similar position with respect to the overlying black Mississippian Caney shale formation, with which their contact is generally gradational. Beds of dark-brown shaly "Mayes" are commonly interbedded with the lighter-colored beds of Sycamore age in the subsurface section north of the western Arbuckle Mountains. Because these beds show such lithologic similarity, they are considered here as the same facies. The thickness of this facies varies from a mere remnant in a localized area in Coal County to approximately 250 feet near its northward transition to the "Siliceous" facies. In the local area of extreme thinning, the Caney section is exceptionally thick, which suggests that the lower Caney is a very shaly phase of "Mayes." Northwest of the Arbuckles and along the north front of the Wichitas, this facies has a typical Sycamore lithology and increases in thickness to approximately 1,000 feet.

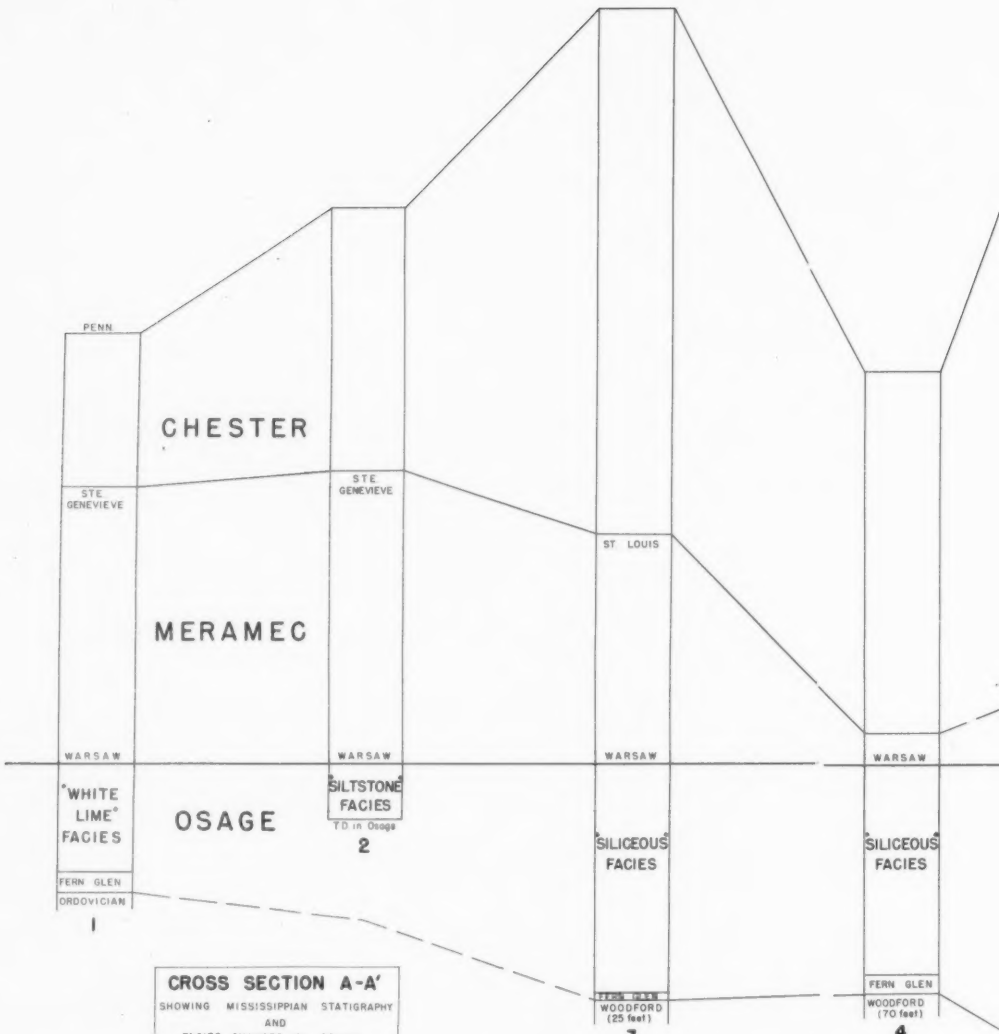
With the exception of the "Mayes-Sycamore" facies, all the different facies are directly overlain by Meramec beds having a characteristic Warsaw lithology, except in areas of truncation by pre-Pennsylvanian erosion.

The cross-section *AA'* graphically expresses the stratigraphic relationship of the different facies of the Osage.

The cross-section *BB'* shows the connection between the "Siliceous" facies and the "Mayes-Sycamore" facies on the west side of the Nemaha Ridge and their intergradation from south to north on the east side.

Buchanan (1927) recognized the gradation of the "Mayes" into the "Siliceous" facies but interpreted the upper cherty beds as indicating the presence of Meramec rocks, younger than Warsaw.

Wallace Lee in 1940 incorporated the beds comprising the "Siliceous" facies in a new subsurface formation, which he



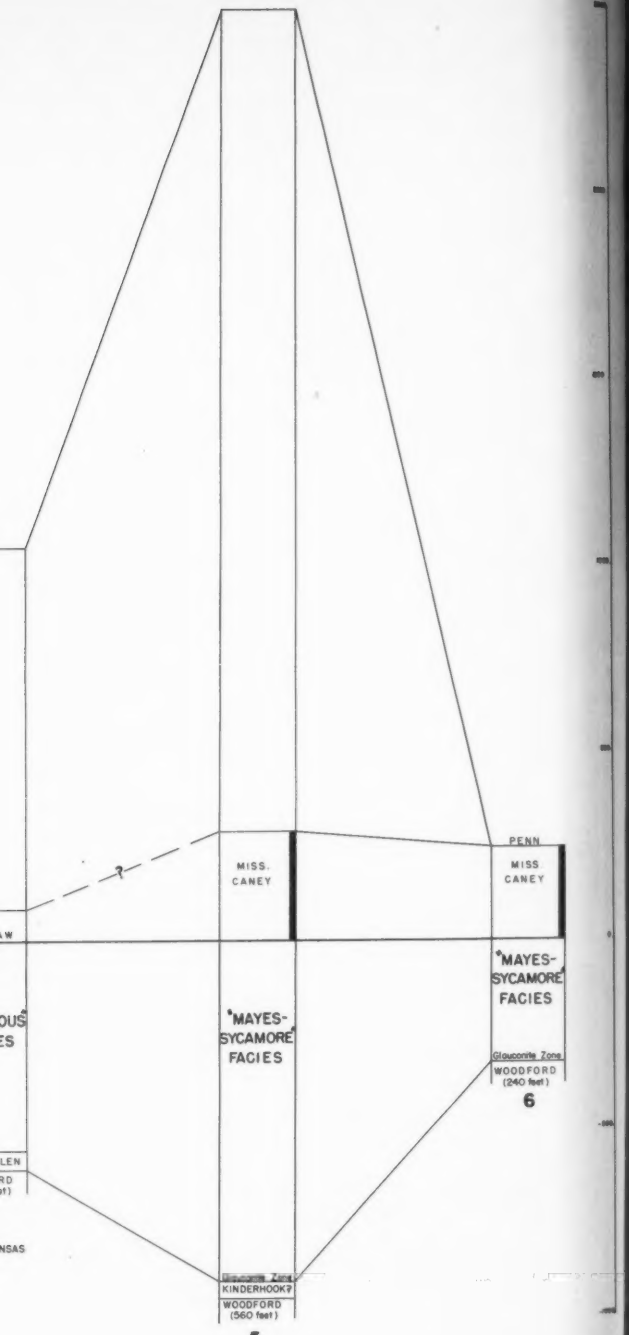
CROSS SECTION A-A'

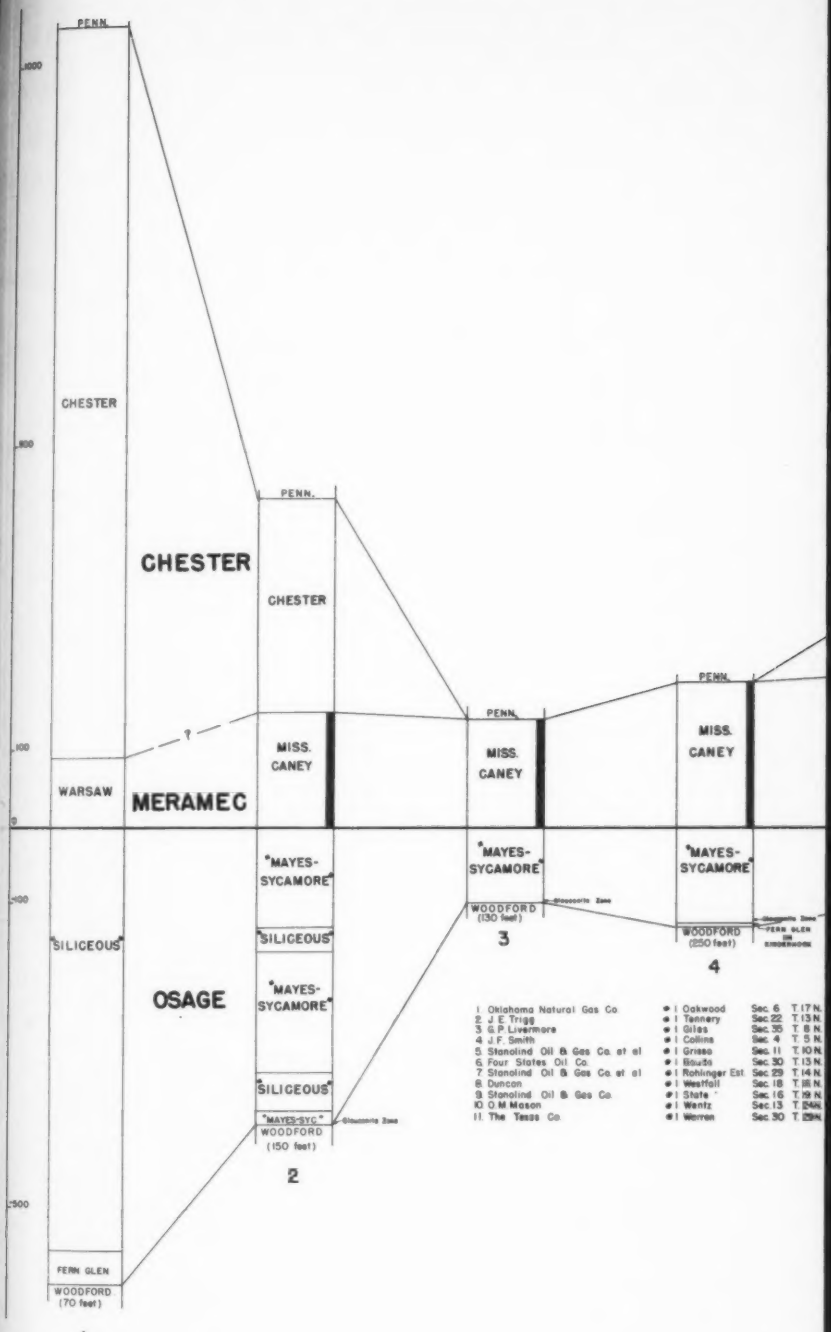
SHOWING MISSISSIPPIAN STATIGRAPHY AND FACIES CHANGES IN OSAGE

BY ERWIN L. SELK 1947

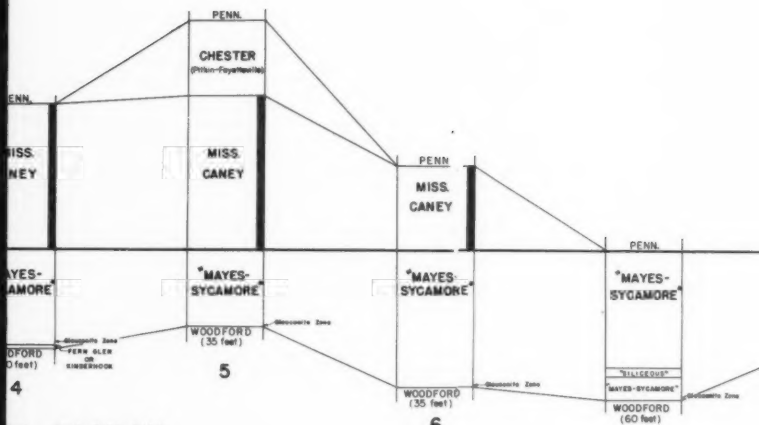
1. Stanolind Oil & Gas #1 Feathers Sec. 15, T 35 S., R 33 W.
2. Sinclair Oil Corporation #1 Hewell Sec. 14, T 26 N., R 26 W.
3. Magnolia Petroleum Corp. #1 Winter Sec. 9, T 19 N., R 20 W.
4. Oklahoma Nat. Gas Co. #1 Oakwood Sec. 6, T 17 N., R 14 W.
5. Sinclair Oil Corporation #1 German Sec. 1, T. 6 N., R 13 W.
6. Amerada Pet Corporation #1 House Sec. 2, T. 1 N., R. 3 W.

SEWARD CO. KANSAS


?
MISS.
CANEY
"MAYES-
SYCAMORE"
FACIES
Glauconite Zone
KINDERHOOK?
WOODFORD
(560 feet)
5
PENN
MISS.
CANEY
"MAYES-
SYCAMORE"
FACIES
Glauconite Zone
WOODFORD
(240 feet)
6



1	Oklahoma Natural Gas Co	● 1	Oakwood	Sec. 6 T. 17 N.
2	J. E. Trigg	● 1	Tennery	Sec. 22 T. 13 N.
3	G. P. Livermore	● 1	Giles	Sec. 35 T. 8 N.
4	J. F. Smith	● 1	Collins	Sec. 4 T. 5 N.
5	Stanolind Oil & Gas Co. et al	● 1	Griesa	Sec. 11 T. 10 N.
6	Four States Oil Co.	● 1	Bowles	Sec. 30 T. 13 N.
7	Stanolind Oil & Gas Co. et al	● 1	Rohlinger Est.	Sec. 29 T. 14 N.
8	Duncan	● 1	Westfall	Sec. 18 T. 18 N.
9	Stanolind Oil & Gas Co.	● 1	State	Sec. 16 T. 19 N.
10	O. M. Mason	● 1	Wentz	Sec. 13 T. 24N.
11	The Texas Co.	● 1	Warren	Sec. 30 T. 29N.



wood	Sec. 6	T. 17 N.	R. 14 W.
ery	Sec. 22	T. 13 N.	R. 7 W.
	Sec. 35	T. 8 N.	R. 5 W.
na	Sec. 4	T. 5 N.	R. 6 E.
so	Sec. 11	T. 10 N.	R. 7 E.
do	Sec. 30	T. 13 N.	R. 6 E.
nger Est	Sec. 29	T. 14 N.	R. 4 E.
ffall	Sec. 18	T. 16 N.	R. 3 E.
e "	Sec. 16	T. 19 N.	R. 4 E.
tz	Sec. 13	T. 24N.	R. 3 E.
en	Sec. 30	T. 29N.	R. 4 E.

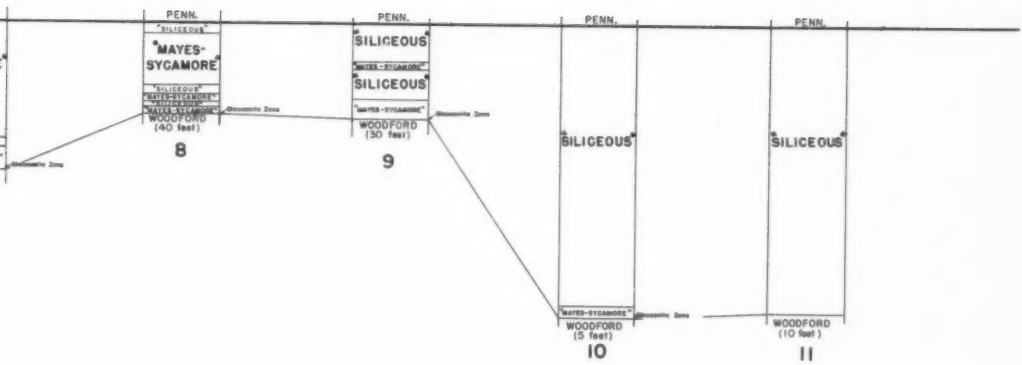
CROSS SECTION B-B'

SHOWING INTERGRADATION OF "SILICEOUS" AND "MAYES-SYCAMORE" FACIES.

by

ERWIN L. SELK

1947


PENN.
"SILICEOUS"
"MAYES-SYCAMORE"
"SILICEOUS"
"MAYES-SYCAMORE"
"MAYES-SYCAMORE"
WOODFORD
(40 feet)
8
PENN.
"SILICEOUS"
"MAYES-SYCAMORE"
"SILICEOUS"
"MAYES-SYCAMORE"
WOODFORD
(30 feet)
9
PENN.
"SILICEOUS"
"MAYES-SYCAMORE"
WOODFORD
(5 feet)
10
PENN.
"SILICEOUS"
WOODFORD
(10 feet)
11

designated the "Cowley formation." The age of the Cowley in Lee's interpretation is Meramecian, older than Warsaw. The abrupt change in lithology from the characteristic white limestone of the Keokuk-Burlington to the dark, silty, siliceous beds occupying the lower part of the Mississippian section throughout the southern tier of counties in Kansas was, according to Lee, a depositional fill, onlapping the margin of a dissected Osage terrain. Other reasons for his interpretation were based on a study of the insoluble residues and the persistence of a glauconite zone at the base of the Cowley, which thinned to the south toward the Oklahoma line in a direction away from the apparent source. The writer has noted that this glauconitic zone can be traced continuously from localities of the Cowley formation into the basal part of the "Mayes," where it is persistent.

CONCLUSIONS

It is apparent that the "Siliceous" facies, the "Siltstone" facies, and the "Mayes-Sycamore" facies are stratigraphically equivalent to the Cowley formation.

The following facts must be considered in determining the age relationship between the white Osage limes and cherts and the Cowley formation: (1) both are overlain by characteristic Warsaw, which in outcrops is recognized as the basal formation of the Meramec; (2) there is no marked variation in relative thickness; and (3) the abrupt change in lithology is not unique.

A parallel situation exists in the subsurface strata of the Illinois Basin. The Keokuk-Burlington rocks grade abruptly into a gray calcareous siltstone and shale facies from northwest to southeast in the vicinity of the Du Quoin flexure. In the southern part of the Illinois Basin the character of these rocks is identical with the dark, cherty, siliceous limestones found in the "Siliceous" facies of northern Oklahoma and southern Kansas. These rocks are classified as Osagian throughout the Eastern Interior region.

The foregoing evidence surely justifies the contention that the "Mayes" of the subsurface in Oklahoma is Osagian.

ACKNOWLEDGMENTS.—The writer is indebted to the Stanolind Oil and Gas Company for permission to publish this report and for the use of subsurface data contained in its files and is also indebted to the various oil companies for permission to use the logs on their respective exploratory wells in the cross sections incorporated with this paper.

The writer is especially indebted to Robert H. Dott, of the Oklahoma Geological Survey, and John G. Bartrum, of the Stanolind Oil and Gas Company, for helpful suggestions in the preparation and editing of this report.

The writer wishes to express appreciation for the helpful discussions with various geologists of this area on matters relating to the problem, especially to M. K. Elias, of the University of Nebraska, Conservation and Survey Division, for permission to refer to his faunal determinations pertaining to the Upper Mississippian.

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THE POSSIBILITY OF A LAND BRIDGE ACROSS NEBRASKA IN MISSISSIPPIAN TIME[1]

E. C. REED
Nebraska Geological Survey

ABSTRACT

The lithologic and paleontologic differences between the Mississippian sediments of the Mid-Continent region and those of the northern Rocky Mountain and Black Hills regions suggest either that the Mississippian seas were not directly continuous between these two regions or that sea connections were greatly restricted. The purpose of this paper is to present and analyze the available subsurface data in Nebraska and surrounding states in the light of this problem. The study is primarily lithologic.

Mississippian sediments are known to be widely distributed in the subsurface of much of Iowa and Kansas, in southeastern and extreme southwestern Nebraska, and in southeastern Colorado. These sediments are lithologically similar to those of the Mid-Continent outcrop areas. Likewise, Mississippian sediments are known to occur widely in the subsurface of much of Wyoming, in western and northwestern South Dakota, in northwestern Colorado, and in extreme northwestern Nebraska. These sediments are lithologically similar to those of the northern Rocky Mountain outcrop areas. However, Mississippian rocks seem to be absent in the subsurface in large areas between these two regions, and the Mississippian sediments of these two regions are lithologically dissimilar.

Therefore, it appears that there was either no direct sea connection between the Mid-Continent and northern Rocky Mountain regions during the Mississippian or that the sea connection was greatly restricted. Mississippian sediments could have been deposited between these two regions and removed by post-Mississippian erosion. It is unlikely, however, that great thicknesses were removed because of the apparent absence of good evidence suggesting facial changes. However, the pre-Pennsylvanian rocks are known to be deeply buried within much of the critical area, and the subsurface has not been thoroughly tested by drilling.

Mississippian sediments seem to be absent in the subsurface of a large part of Nebraska. This condition suggests the possibility that a land bridge extended across Nebraska during Mississippian time and that there was no direct sea connection between the Mid-Continent and the northern Rocky Mountain regions during the Mississippian. It is apparent (1) that many factors should be considered in arriving at a definite conclusion; (2) that the Mississippian cannot be treated as a single unit but that special considerations must be given to the possibility that sea connections may have existed at certain times during the Mississippian and not at other times; (3) that some areas have not been explored sufficiently for positive conclusions; and (4) that the subsurface and surface evidence in states adjoining Nebraska must be considered as important parts of the picture.

[1] Manuscript received December 26, 1947.

Although a number of deep wells have been drilled in Nebraska, many of those in critical areas have not been drilled deeply enough to reach Mississippian or pre-Mississippian rocks. Figure 1 shows the locations of test wells drilled to rocks of Mississippian and pre-Mississippian age. Note that large untested areas exist in northeastern, north-central, western, and southwestern Nebraska. However, there is a large area in the central part of the state where the Mississippian is undoubtedly absent, and the southward thinning of the Mississippian in northwestern Nebraska suggests that these rocks may be expected to be absent in much of the "panhandle" part of western Nebraska.

Whether or not the Mississippian is represented in the east-central Nebraska Basin is open to some question because of differences of opinion among qualified subsurface geologists. A succession of dense, very finely crystalline limestones

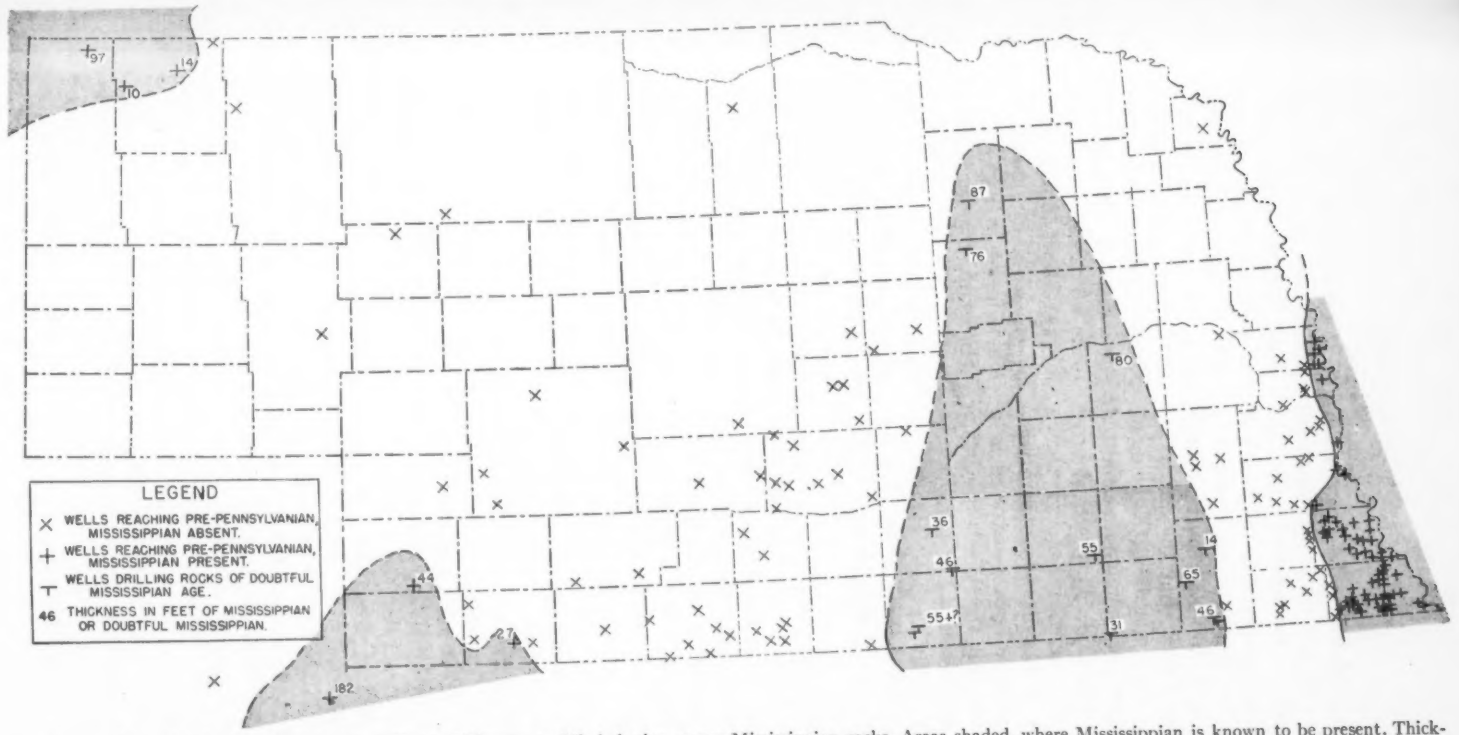


FIG. 1.—Map showing location of wells drilled in Nebraska to Mississippian or pre-Mississippian rocks. Areas shaded, where Mississippian is known to be present. Thickness of Mississippian penetrated shown, except in areas of concentrated drilling. Doubtful Mississippian rocks believed to be post–Cedar Valley Devonian by some subsurface geologists.

immediately underlies the Pennsylvanian in this area and rests, with apparent unconformity, upon relatively thin Devonian dolomites, probably of Cedar Valley age. These limestones are believed by some geologists to be Devonian, though post–Cedar Valley; but the writer believes that they may be of Kinderhook age and, therefore, should not be omitted from consideration. Their relation to overlying and underlying rocks is shown in figure 2. Rocks of undoubted Mississippian age have been penetrated in a number of wells in the Forest City Basin region in southeastern Nebraska, in several wells near the Kansas-Nebraska line in southwestern Nebraska, and in a few wells in the northwestern part of the state (fig. 1).

The dominant anticlinal structural features of Nebraska are the Cambridge Arch, which is a north-northwest extension of the Central Kansas Uplift and continues toward or into the Black Hills of South Dakota, and the Table Rock–Nehawka Arch, a north-south structural high, which is a northward continuation of the so-called "Nemaha Ridge" of Kansas. Post-Mississippian, pre-Pennsylvanian uplift took place along both these structural highs, and the Mississippian thins by truncation as the structurally high areas are approached. The thinning of the Mississippian by truncation toward the Table Rock–Nehawka Arch is shown in figures 3 and 4. In areas of close control the shale of Kinderhook age definitely thins to the northwest and north, and the individual formations in the Osage-Meramec show some north-northwest thinning. The beds of Chouteau age, however, preserve their rather uniform thickness where present and actually thicken in the eastern Nebraska Basin if the pre-Pennsylvanian, post–Cedar Valley rocks in that area should prove to be of Chouteau age.

If we eliminate the complications introduced by the Cambridge and Table Rock–Nemaha arches and assume that the Mississippian sea covered large areas of these uplifts and that the Mississippian rocks were removed by erosion prior to the deposition of Pennsylvanian sediments, there remains a broad northeast-southwest area devoid of Mississippian rocks which cannot be easily explained by post-Mississippian, pre-Pennsylvanian erosion along known lines of post-Mississippian uplift.

In comparing the relationships of the rocks in Nebraska with those in adjoining states (fig. 5), we note that this broad area lacking Mississippian rocks appears to continue northeastward into southeastern South Dakota, northwestern Iowa, and southern Minnesota and that Mississippian rocks appear to be absent in a broad area in east-central Colorado and southeastern Wyoming. This strongly suggests a land barrier between the Mid-Continent and the northern Rocky Mountain regions during much of Mississippian time. The sparse subsurface control in much of the critical area of western Nebraska and eastern Colorado precludes definite conclusions, however, as future deep drilling may encounter buried Mississippian outliers in structurally low areas.

It seems logical to conclude that it is very unlikely that great thicknesses of Mississippian rocks were deposited across Nebraska between the Mid-Continent and the northern Rocky Mountain regions and later removed. First, it is reasonable to expect that some of the "chance" drillings in this region would have encountered remnants of Mississippian rocks. Second, if large amounts of Mississippian rocks had been removed in early Pennsylvanian time, we should expect to find detrital materials from Mississippian sources in early Penn-

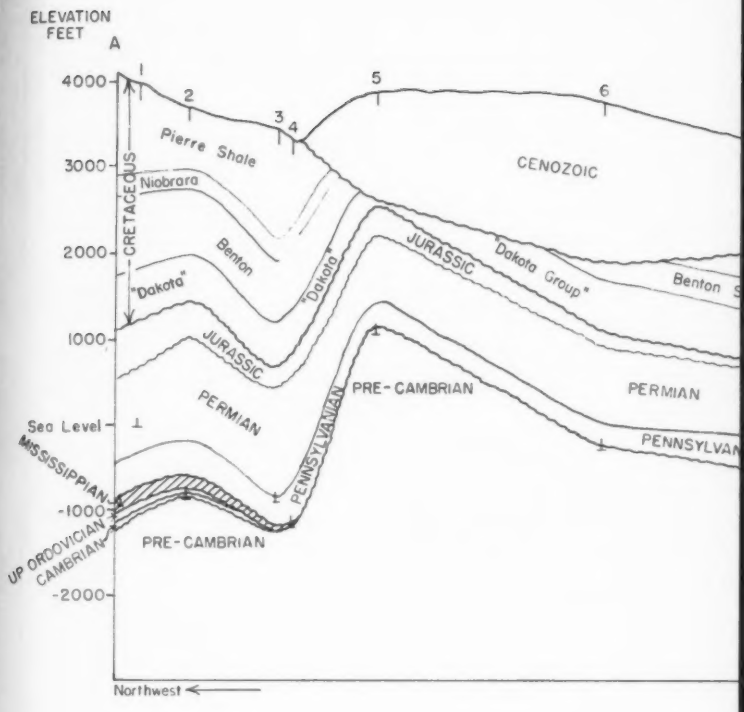
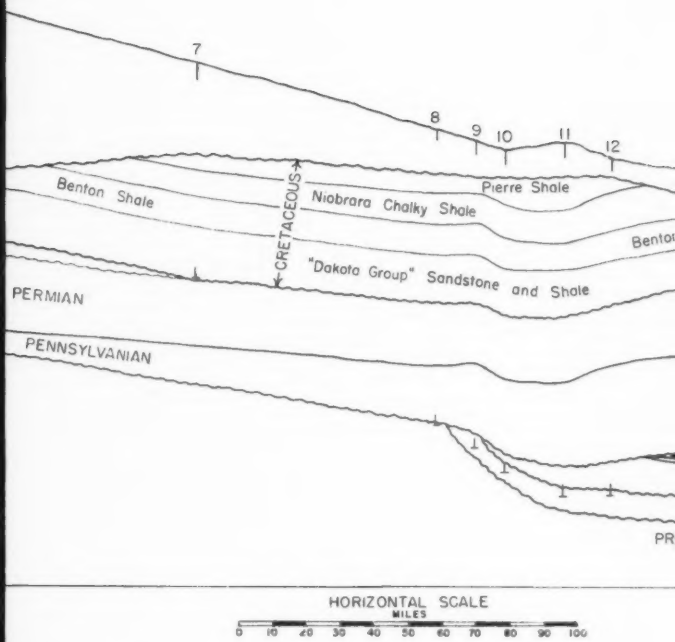
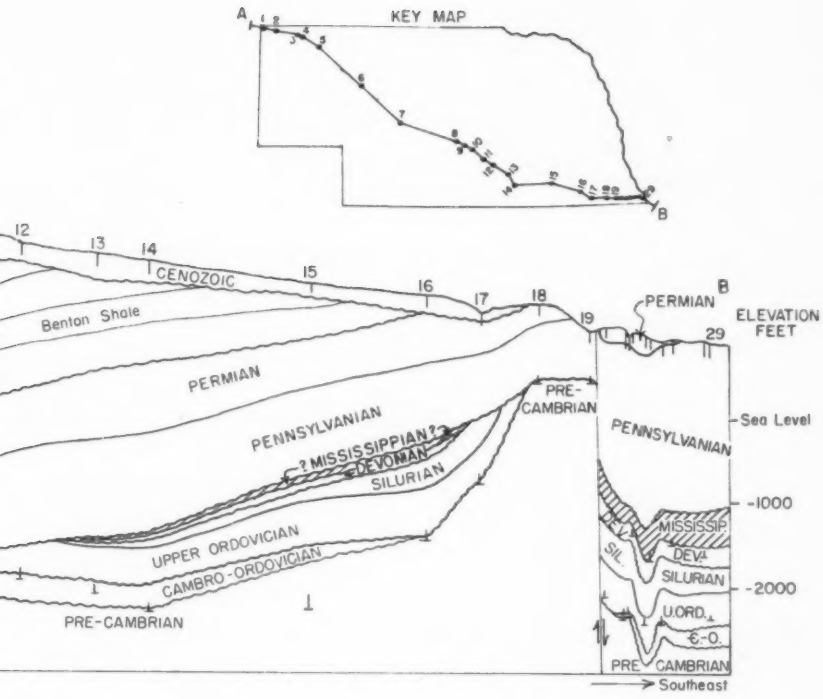


FIG. 2.—Northwest-southeast profile section across Nebraska showin
Nehawka Arch (wells 18 and 19), east-central Nebraska Basin (wells 9–17



braska showing relative position of Mississippian strata (*cross-hatched areas*). Not
in (wells 9–17), Cambridge Arch (wells 5–8), and western Nebraska Basin (wells 1–



reas). Note principal structural features: Forest City Basin (wells 20–29), Table Rock–
in (wells 1–4).

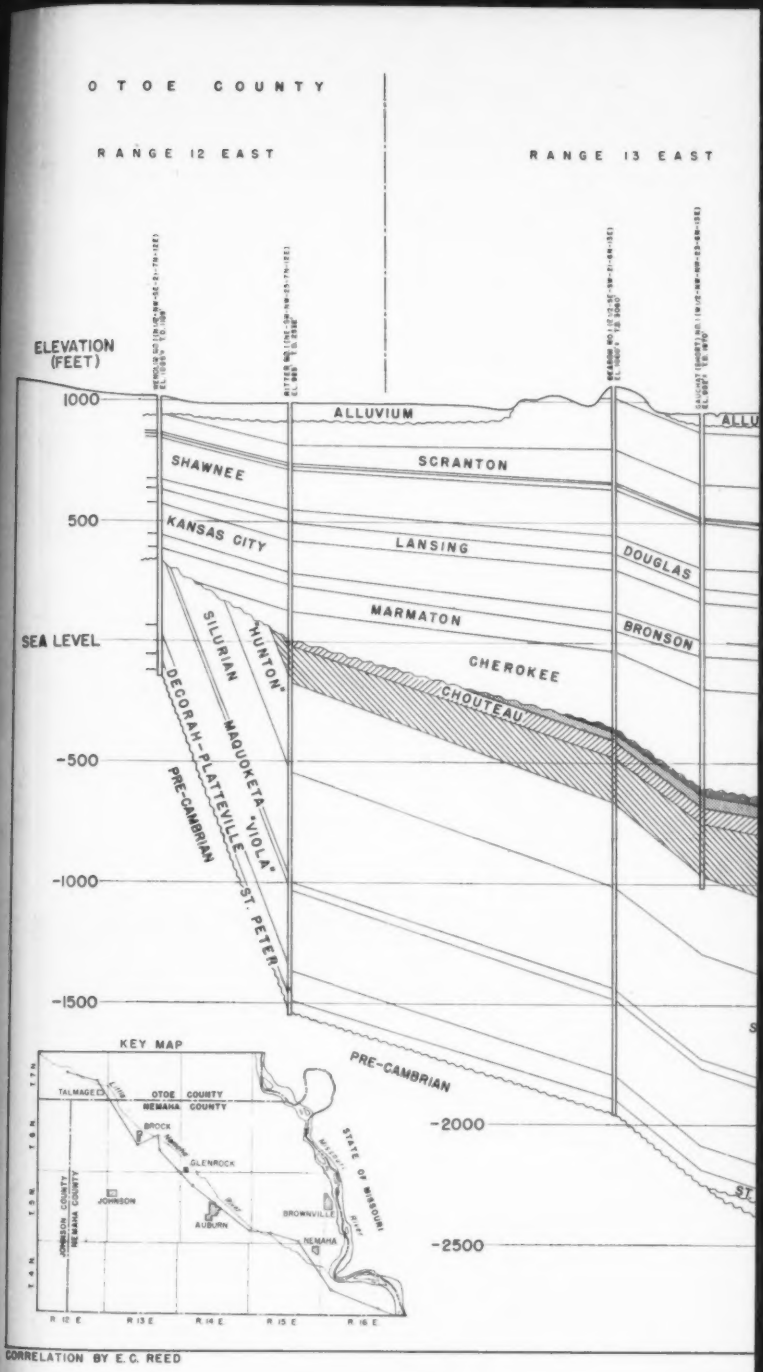
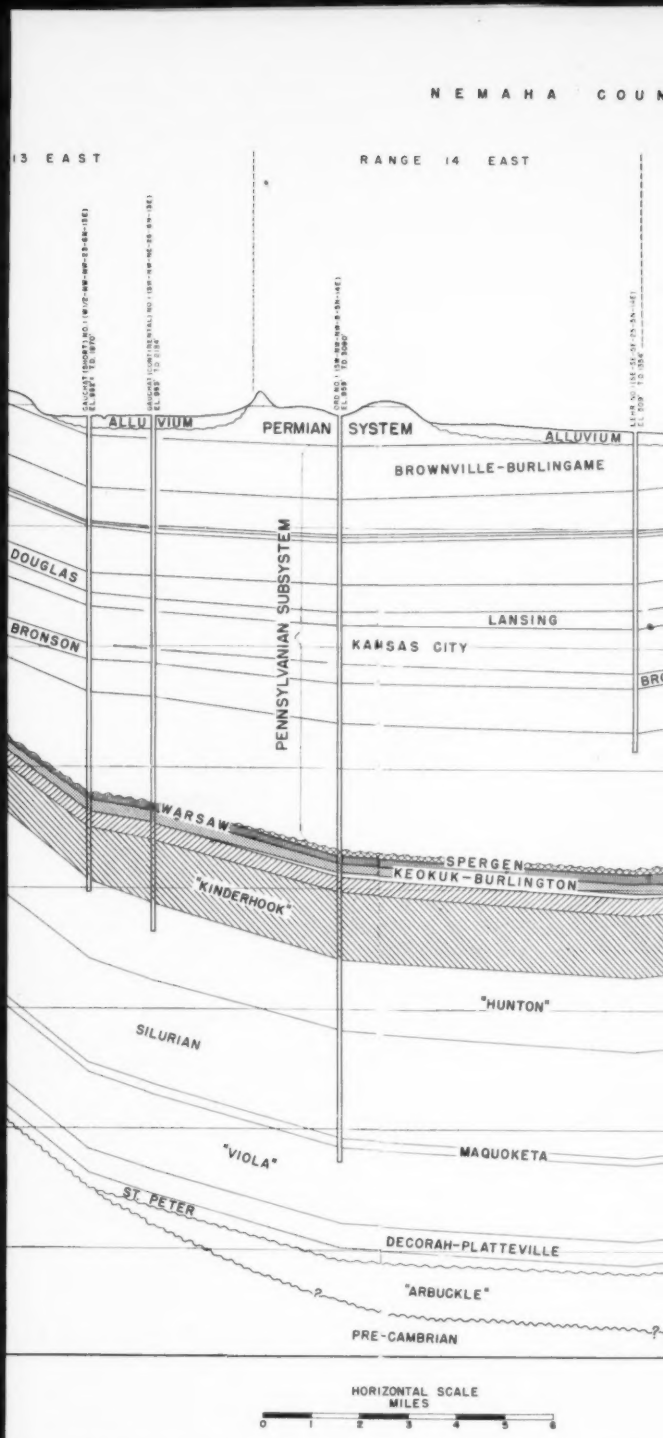
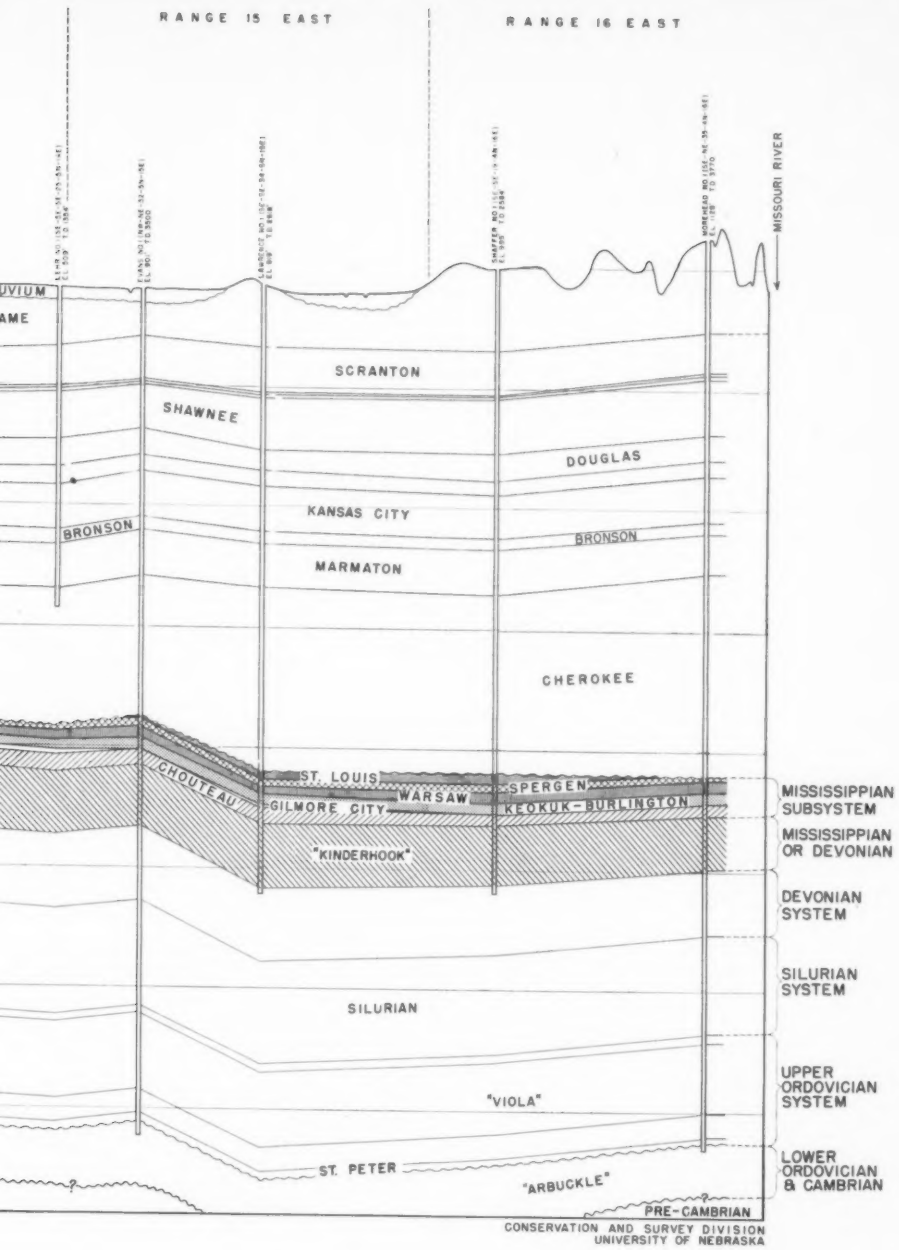


FIG. 3.—Northwest-southeast profile section across Nemaha County and part of Otoe C
west. Interval labeled "Kinderhook" represents Chattanooga and Boice shales, now known t



d part of Otoe County, southeast Nebraska, showing position of Mississippian
les, now known to be Mississippian.

COUNTY



issippian strata in Forest City Basin and relation to Table Rock–Nehawka arch to north-

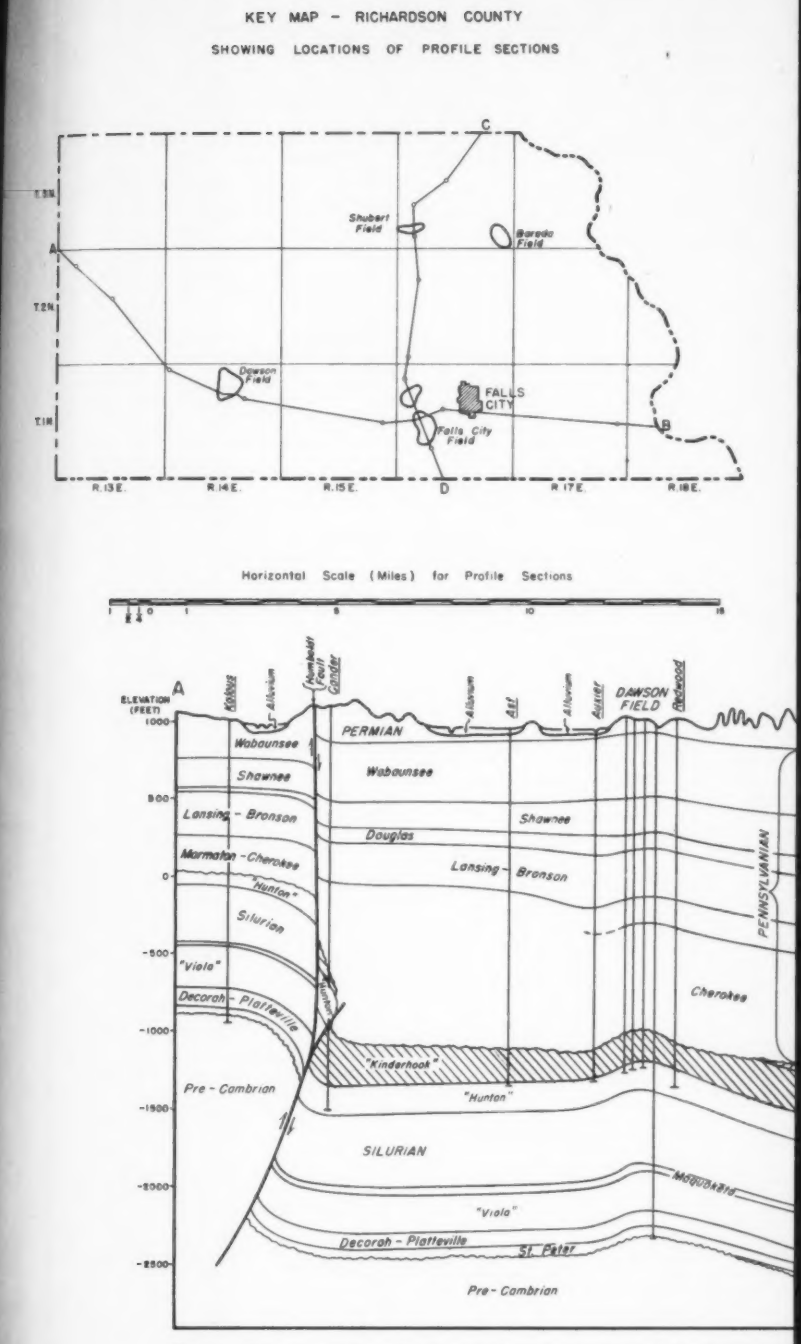
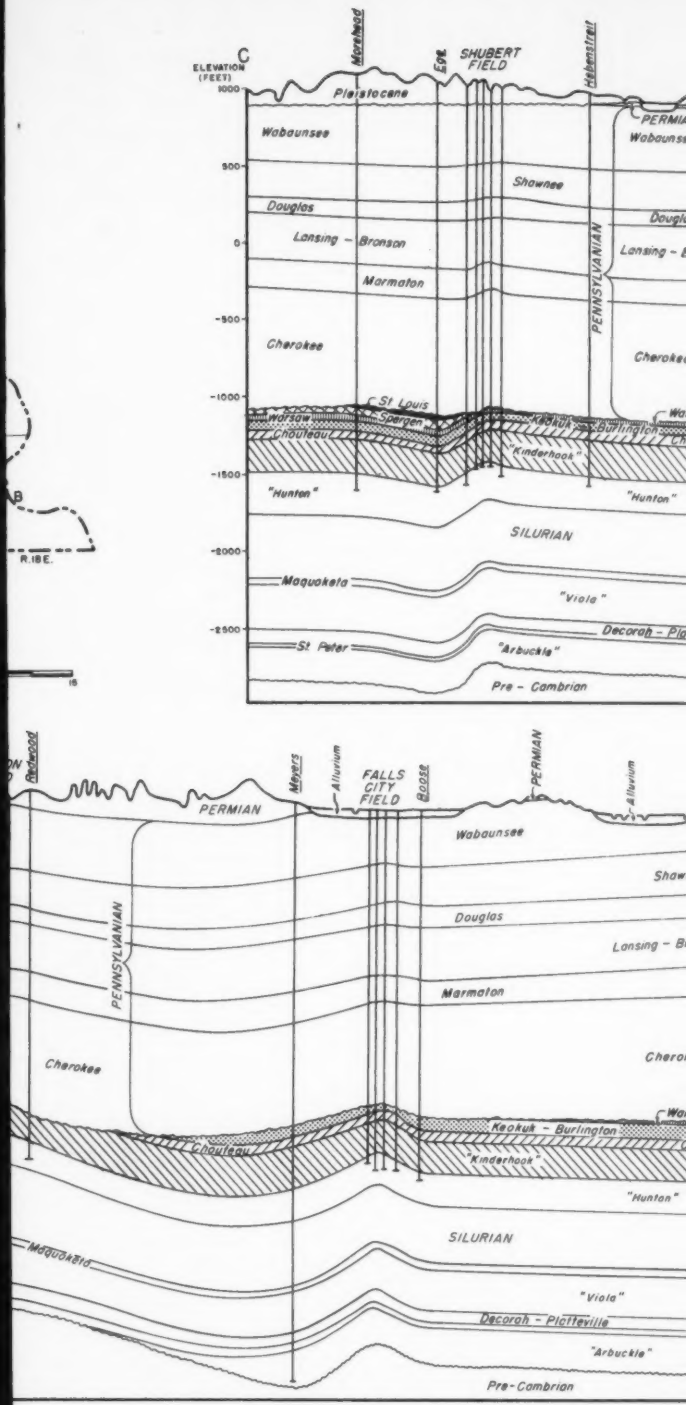
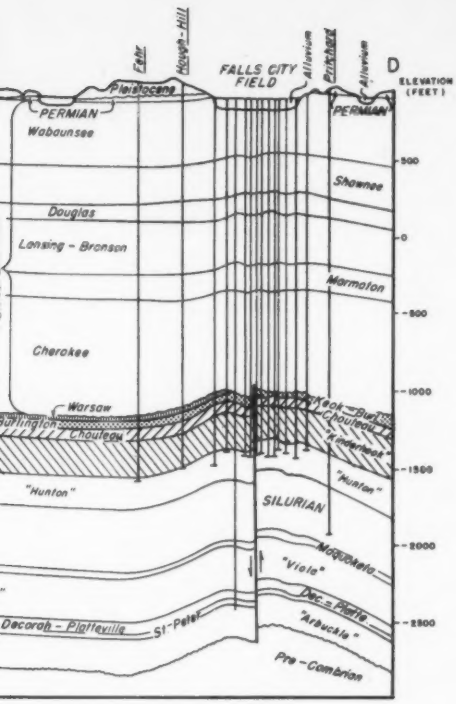
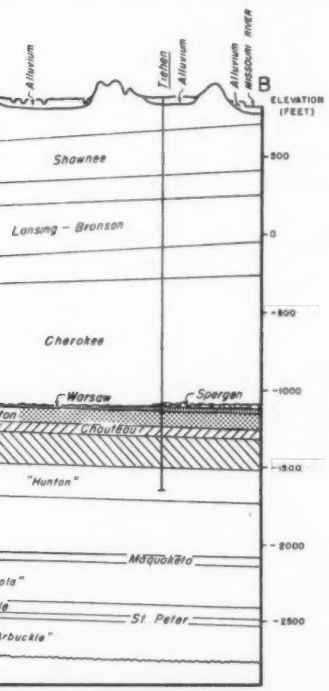


FIG. 4.—East-west and north-south profile sections across Richardson Count
er and younger rocks in Forest City Basin. Oil fields shown on key map produc
shales of Lower Mississippian age.



ichardson County, southeast Nebraska, showing relation of Mississippian rocks (*sh*
key map produce from Devonian dolomites. "Kinderhook" interval includes Chat





n rocks (*shaded areas*) to old-
ludes Chattanooga and Boice

sylvanian deposits of the basinward parts of the region. However, re-worked Mississippian materials seem to be missing except along the more southerly extensions of the Cambridge and Table Rock–Nehawka arches.

In much of this area in Nebraska, Pennsylvanian rocks rest upon the pre-Cambrian. The considerable depth of weathering on the pre-Cambrian surface (more than 60 feet in some places) suggests a considerable time interval, probably longer than might be expected if the pre-Cambrian had been protected by Mississippian and older Paleozoic rocks and exposed to weathering for only shorter intervals of geologic time.

The post-Kinderhook Mississippian rocks of the northern Mid-Continent area seem to preserve their lithologic identity over wide areas in northern Kansas and southern Nebraska but tend to disappear northward by thinning and overlap. Moreover, the Mississippian of the northern Rocky Mountain region bears little or no lithologic similarity to the post-Kinderhookian Mississippian of the Mid-Continent region, nor does it show any tendency toward facial change in a southeast direction. Therefore, in view of all the evidence, it seems improbable that there was a post-Kinderhookian–Mississippian sea connection across Nebraska.

FIG. 5.—Generalized Mississippian distribution map of Nebraska and adjoining states based on published and unpublished data showing generalized subsurface thickness of Mississippian limestones and dolomites in eastern Colorado, Kansas, southern Nebraska, Missouri, and Iowa. Area of no Mississippian rocks generalized and includes small thickness of Mississippian in a few places near the area margins.

The evidence that a land barrier existed in this region throughout Kinderhookian time is not conclusive, however, because we cannot detect any marked northward or northwestward thinning of the Kinderhook limestones, except by trunca-

tion. Moreoever, if the doubtful limestone interval in the east-central Nebraska Basin (fig. 1) is truly Kinderhookian and not Devonian in age, some facial change between the Mid-Continent and the northern Rocky Mountain regions is indicated, as these rocks, especially in their northern extension, are not dissimilar lithologically to the Mississippian limestones of northwestern Nebraska and adjoining southwestern South Dakota.

ACKNOWLEDGMENTS.—The author has had the opportunity of checking all the subsurface evidence in Nebraska but has had to rely on published data in adjoining states, augmented by personal communications with survey personnel in Iowa, Kansas, South Dakota, and Wyoming. He is especially indebted to Dr. H. G. Hershey, state geologist of Iowa; Mr. Wallace Lee, of the United States Geological Survey and Kansas Geological Survey; Dr. C. L. Baker, of the South Dakota Geological Survey; and Dr. H. D. Thomas, state geologist of Wyoming, for assistance in their respective areas. He realizes that much pertinent subsurface information exists in the files of oil companies that have been engaged in regional studies, but no attempt has been made to obtain these data because much of it is confidential. He is also indebted to the authors listed in the appended bibliography for their important contributions.

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SOME PROBLEMS OF MISSISSIPPIAN STRATIGRAPHY IN SOUTHWESTERN UNITED STATES[1]

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University of Arizona

ABSTRACT

The southwestern Mississippian problems discussed include the relation of Lower Mississippian strata to their subjacent rocks, especially the problems involved in the evaluation of the Ouray limestone and the Percha formation as possible transitional units from the Devonian. Further problems are indicated in the relation of the Escabrosa limestone, with an impoverished brachiopod fauna, to the Redwall limestone, which is rich in brachiopods, and in the interrelation of the fossiliferous Lower Mississippian strata of Nevada, Utah, and Colorado. Although insufficient knowledge of the regional stratigraphic paleontology is a serious handicap for interpretation, the relation between the autochthonous forms of the southwestern Lower Mississippian and the species characteristic of the Mississippi Valley Basin suggest a westward migration from the latter region. However, the nature of the ways of communication is still problematical. For instance, the abundance of typical Mississippi Valley species and the lack of southwestern brachiopods in the Lower Mississippian of New Mexico do not favor a direct connection with the Redwall and the Escabrosa basins.

The Upper Mississippian Paradise formation of southeastern Arizona, most readily comparable paleontologically and stratigraphically to the standard Upper Mississippian of the Mississippi Valley, still has no other counterparts in the Southwest and is not easily traceable eastward through New Mexico and Texas or through Chihuahua and Coahuila in Mexico. The southernmost outpost of the comparable western unit, the Brazer limestone, with stratigraphically diffused paleontological indices and without *Archimedes* facies, is a long distance to the north, which suggests research problems in the intermediate areas, whereas the recent finds of Mississippian faunas in Sonora suggest the possibility of a southwestern orientation of a late Mississippian passageway in agreement with the pre-Mississippian paleogeographical setting and in common with the general direction of other Paleozoic outlets of that region.

RELATION OF THE ESCABROSA AND REDWALL LIMESTONES IN ARIZONA AND OF THE LOWER MISSISSIPPIAN STRATA IN COLORADO AND OTHER SOUTHWESTERN STATES TO THEIR SUBJACENT ROCKS

The generally accepted standard stratigraphic units of the southwestern Lower Mississippian are the Escabrosa limestone in southeastern Arizona, the Redwall limestone in north-central Arizona, the Lake Valley formation in New Mexico, the Monte Cristo limestone in Nevada, the Leadville limestone in Colorado, and the Madison limestone in Colorado, Utah, and southeastern Idaho.

ESCABROSA

In the southeastern part of Arizona the protean Devonian Martin limestone of Ransome (1904) is composed of several distinct stratigraphic units which may be readily correlated on paleontological evidence with the well-known standard Upper Devonian divisions in Iowa. Thus, in the Mescal Mountains south of Globe the strata between the Cambrian Troy quartzite and the Escabrosa limestone contain the fauna of the Independence shale of Iowa (with *Macgeea parva, Petrocrania famelica, Schizophoria amanaensis, Hypothyridina emmonsi, Spirifer strigosus,* etc.); at Superior, beneath the Escabrosa, is the Martin limestone proper, which is the Arizona equivalent of the Hackberry shale (Lime Creek) of Iowa as originally defined (with *Spirifer hungerfordi* and *Pachyphyllum woodmani*), whereas below the Martin limestone and separated from it by a cross-bedded sandstone are limestone beds with the index fossils of the Cedar Valley limestone of the Iowa sequence (*Sp. iowensis, Sp. cedarensis, Sp. euruteines,*

[1] Manuscript received February 2, 1948.

etc. [Stoyanow, 1936, p. 489]). There are also earlier fossiliferous Devonian strata between the Cedar Valley equivalent and the Troy quartzite below; but whether these beds contain the same assemblage of Independence fossils as is present in the Mescal Mountains has not been ascertained, and it is still unknown whether all three units of the Iowa Upper Devonian are represented in a single section anywhere in southeastern Arizona.

Stainbrook (1947, pp. 297–302) reports fossils of Percha age collected near the top of Mount Martin at Bisbee. He correlates the Percha formation of New Mexico with the Ouray limestone of southwestern Colorado (as redefined by Kirk, 1931, p. 222) but considers the Percha to be of early Mississippian age. Whatever the age of the Percha fauna—whether it is Devonian, Mississippian, or, like the Malevka-Murajevna, a transitional fauna—it is most probably not a time equivalent of the *Paurorhyncha endlichi* fauna of the Ouray limestone. *Paurorhyncha cooperi*, which Stainbrook cites both from the Percha formation of New Mexico and from the section of Mount Martin at Bisbee and which he compares with *P. endlichi*, has been located recently (Stainbrook, 1947, pl. 47, fig. 1, holotype only) by W. B. Loring, 95 feet below the base of the Escabrosa limestone of the Swisshelm Mountains in the extreme southeastern part of Arizona, near the New Mexico border. However, the lowest known occurrence of *P. endlichi*, near Burch on Pinal Creek, northwest of Globe,[2] is only a few inches above the topmost reef of *Hexagonaria* (*Acervularia davidsoni* of various authors). Because both the reef and *P. endlichi* occur in the same lithological unit, a Mississippian age for this species is not possible.

The late Devonian strata in southeastern Arizona show marked variability, a rapid change in faunal succession, and a spotty distribution. With the exception of the Superior area, the equivalents of the Cedar Valley and of Hackberry are rarely present in the same section. The Devonian strata and the Escabrosa are apparently conformable. The apparent conformity may be an illusion arising from the striking lithological and physiographic contrast between the easily eroded, slope-forming Devonian strata and the bold relief of the cliff-forming Escabrosa limestone. Certainly, however, there was no communication through Colorado between Arizona and the Iowa Devonian basins. The patchy distribution of the Independence fauna in the Southwest is further illustrated by its unexpected discovery in isolated areas, such as New Mexico near Alamogordo (Stainbrook, 1935) and the Mescal Mountains of Arizona. On the other hand, a communication between the Devonian seas of Arizona and southwestern Colorado seems to have been established at the close of Devonian time (as inferred from the distribution of the *P. endlichi* fauna), and it is certainly pertinent to inquire, therefore, whether there actually are transitional faunas and gradational deposition between the Devonian and the Mississippian within such units as the Ouray limestone and the Percha formation.

REDWALL

The Redwall limestone—the Lower Mississippian stratigraphic unit of north-central Arizona—rests on the uneven surface of different older strata. Observations indicate that the basin in which the

[2] The collected specimen is identical with the type illustrated by White (1883, pl. 33, fig. 4*a* only).

Redwall formed continued to the northwest and that the thickness of the Redwall appreciably decreases both to the northeast and to the southeast. Wooddell (1927) was the first to notice the unconformable contact between the Devonian Jerome formation and the Mississippian Redwall limestone near Jerome, Arizona. The regional unconformity is more apparent if broader areas are considered. In the vicinity of Jerome certain younger Devonian strata, like the Island Mesa beds (Stoyanow, 1936, p. 500; 1942, p. 1271), are present only locally. The overlap of the Redwall limestone on the Cambrian platform is well shown in the Grand Canyon sections.

OURAY, PERCHA, AND LEADVILLE

In central Colorado the Lower Mississippian Leadville limestone is readily distinguished from the Devonian strata. Kirk (1931) has established a Devonian-Mississippian unconformity in the triangle outlined by Glenwood Springs, Salida, and Leadville. He introduced the term "Leadville" for the Lower Mississippian strata of that area, extended it also to cover the Lower Mississippian part of the Ouray limestone, and restricted the latter name to the Devonian part.[3] However, in the San Juan region and especially in the type area of the Ouray limestone the unconformity has not been so clearly demonstrated. An uninterrupted continuity of deposition without any appreciable change in lithology from the Devonian to the Mississippian has been described in a number of publications (Cross and Howe, 1905, 1907; Cross and Ransome, 1905; Cross, 1910). It is interesting to note in this connection that, according to the original description of the type Ouray limestone by Spencer (1900, p. 126), the thickness of strata between the Devonian part of the limestone and the upper part, which was believed to belong in the Upper Carboniferous, amounts to only a few feet. This led Spencer to the conclusion that either there is a gap in the sequence which represents Mississippian time or else some unfossiliferous strata in the lower part of the limestone, but above the fossiliferous Devonian zone, may be of Mississippian age. In other words, an idea of disconformity was introduced with the original description. Certain lithological differences between the Devonian and the Mississippian parts of the sequence at Ouray were pointed out by Kindle (1909, pp. 6–7, 13), who was unable to find Devonian fossils at the type locality. According to Kirk (1931, p. 233), the type area ". . . is the place where it is most difficult to separate the two stratigraphic units. The exposures are either in cliffs difficult of access or badly overgrown with timber." The fossiliferous localities in the vicinity are few, and in some areas no fossils have been found. In an earlier paper Burbank (1930, pp. 158–161) stated that the Ouray limestone at Ouray is divisible into two lithological units, of Devonian and Mississippian age, respectively. The Devonian part is approximately 68 feet thick. The only fossiliferous Devonian zone located is about 15–20 feet above the base and, according to Dr. Kirk, contains a characteristic Devonian Ouray fauna. The upper limit of the Devonian was placed at the base of a thin-bedded, blue-gray limestone with nodules of chert. In some

[3] Kirk thus reverted to the original definition of Spencer (1900, p. 126): "The formation name, Ouray limestone, is proposed for the only member of the section which is definitely shown by its fossils to be of Devonian age, from the prominent occurrence in the vicinity of Ouray at the junction of the Canyon creek with the Uncompaghre River."

places a limestone breccia occurs in this unit, in others the base of the Mississippian seems to be marked by a sandstone.

It seems that the break between the Upper Devonian and the Lower Mississippian in Colorado was smallest in the San Juan region, and it is probable that in certain parts of southwestern Colorado deposition continued without interruption. From the standpoint of stratigraphical paleontology a locality northeast of Animas, Colorado, is of special interest. Here Endlich (1876, pp. 211–214, Station 48 on the map, p. 412) collected the types of *P. endlichi*, forms identical with the plesiotypes associated with the Upper Devonian faunas in Arizona and probably different from the majority of specimens referred to that species in the literature.

As noted above, Stainbrook (1947, p. 302) believes the Percha fauna to be most closely related to the Devonian fauna of the Ouray limestone. Observing that Kindle (1909) showed a similarity between the Ouray and Percha faunas, he says: "If the Percha be Mississippian, the Ouray is Mississippian also, and the Devonian is but scantily represented in Colorado." I think, however, that this correlation of the two faunas has not been satisfactorily proved. The fossils listed from the Ouray of Colorado and the close relation of the beds with typical *P. endlichi* to strata with the characteristic Hackberry shale faunas in certain parts of Arizona oppose this view. The abundance of productids in the Percha fauna described by Stainbrook, and especially such genera as *Avonia*, *Buxtonia*, *Krotovia*, and *Echinoconchus*, altogether unknown from the Ouray of Colorado, in which Productidae are represented only by productellids (Johnson, 1945, p. 41), strongly favors a younger age for the Percha if it is considered a single time unit. It is significant, however, that nearly all productids described by Stainbrook came from the Bella member, i.e., the top of the Percha formation, and the possibility that there are faunas of two ages in the Percha cannot be excluded.[4] On the other hand, if the Percha fauna is accepted as a unit (biochron) of relatively short range, then Percha time may be included in the hiatus between the Ouray and the Leadville in central Colorado. The presence of a similar break at Ouray, where neither fossils nor interruption in sequence is definitely known between the *P. endlichi* and *Spirifer centronatus* zones, is more questionable. Stainbrook's views bring back, on a broader basis, the old controversy which constitutes one of the current Mississippian problems of the Southwest.

OTHER INTERCORDILLERAN STATES

In southeastern Nevada the Lower Mississippian Monte Cristo limestone rests on the Devonian Sultan limestone without a perceptible unconformity (Hewett, 1931, pp. 15–17). Farther northeast, in the Muddy Mountains, the base of the Lower Mississippian is indicated by an irregular surface of the limestone assigned to the Devonian (Longwell, 1928, p. 28), whereas in central and eastern Nevada and western Utah the Lower Mississippian strata rest on different formations essentially of middle and late Devonian ages (Westgate and Knopf, 1932, pp. 17, 19–20; Nolan, 1943, pp. 153–154). In the Gold Hill mining district, Utah, the base of the Madison is obscured by a thrust fault (Nolan, 1935, pp. 21, 24–27, figs. 3–5),

[4] Stainbrook (1947, p. 298) himself states that his interest in the described material was essentially paleontological and that "while collecting from the Percha no stratigraphic studies were made other than to locate the top and bottom of the formation, if exposed, and to verify the position of the beds with respect to adjacent formations."

but an unconformity is inferred on stratigraphic evidence. In the Stockton-Fairfield quadrangles there is a definite erosional break between the Madison limestone and the supposed Jefferson (Devonian) dolomite (Gilluly, 1932, p. 22). In southeastern Idaho the base of the Madison limestone is not exposed (Mansfield, 1927, p. 60).

STRATIGRAPHIC EVALUATION OF THE SOUTHWESTERN LOWER MISSISSIPPIAN FAUNA

Progress in paleontological stratigraphy of the southwestern Mississippian has been greatly handicapped by the lack of adequate studies and analyses of the fossil material used for correlations. The onerous and ever increasing work of identifying the fossils collected by the field parties of the United States Geological Survey was for years executed by the late G. H. Girty, without opportunity for sufficient description and illustration, and therefore resulted in deductions often not wholly acceptable to others. Correlation of strata from the Mexican border to Idaho by a single paleontologist, of no matter how great experience, could not be infallible and has resulted in wide generalizations and probably some errors. The practice of borrowing paleontological illustrations from publications on strata in certain cases many hundreds of miles distant and of doubtful relation to the formations of a given locality, the fossils of which they were supposed to characterize, is actually harmful to detailed stratigraphic analysis. Such conditions could not contribute much to the progress of paleontological stratigraphy and paleogeography of a vast region, and the need of research to bring these branches of regional geology to the level of other geological studies is considerable.

ESCABROSA LIMESTONE

Table 1 shows species of correlative value from the Escabrosa limestone which also occur in the lists from sections studied in the Southwest and in southeastern Idaho.

TABLE 1*

	1	2	3	4	5	6	7
Syringothyris "carteri"	.....	Sp.?	.....	Aff.	.....	×	.....
Spirifer centronatus	×	×	?	×	×	×	×
Leptaena analoga	.....	×	.....	×	.....	.....	×
Chonetes loganensis	×	×	×	×	×	×	×
Rhipidomella thiemi	.....	×	.....	.....	.....	?	.....
Linoproductus ovatus	×	×	×	×	×	.....	×
Camarotoechia metallica	×	×	.....	×	Cf.	×	×
Triplophyllum? several sp.	×	×	×	×	.....	?	×
Euomphalus luxus	.....	.....	?	×	×	.....	×

* Index fossils of the Escabrosa limestone in relation to the faunal lists from other characteristic Lower Mississippian sections of the Southwest and southeastern Idaho. 1 = Pioche district, Nevada; 2 = Good Springs, Nevada; 3 = Gold Hill, Utah; 4 = Stockton-Fairfield, Utah; 5 = Wasatch and Uinta, Utah; 6 = Colorado; 7 = southeastern Idaho.

The presence of *Syringothyris* in the Escabrosa limestone (Ransome, 1904, pp. 42–54) has not been corroborated by subsequent workers. It is not improbable that *"Syringothyris carteri"* in Ransome's list of fossils from Bisbee belongs to *Syringospira*, a genus established by Kindle (1909, pp. 28–30, pl. 7, figs. 8–8*d*; pl. 8, figs. 1–1*a*) on material from the Percha formation at Hillsboro, New Mexico, three years after the publication

of Ransome's monograph on the Bisbee quadrangle and therefore probably not known to Girty at that time. *Syringospira prima* Kindle has been cited by Stainbrook (1947, p. 298) from the strata near the top of Mount Martin at Bisbee, that is, close to the base of the Escabrosa limestone at its type locality. As seen from table 1, *S. typa* (*S. carteri* auctorum) has been definitely indicated only in the Crested Butte quadrangle, Colorado (Johnson, 1945, table 7).

Among the varieties of *Sp. centronatus*, a form shorter and wider and also less mucronate than any other of the described types referred to Winchell's species (White, 1877, pl. 5, figs. 8*a*–8*b*; Hall and Whitfield, 1877, pl. 4, figs. 5–6), deserves special consideration because of its definite stratigraphic position and wide distribution. In the Escabrosa limestone this variety invariably occurs with abundant "small cup corals" which were referred by Girty to *Triplophyllum* and *Menophyllum* in the material collected from both the Escabrosa and the Redwall limestones (Ransome, 1904, p. 50; 1916, pp. 143, 147, 152; Darton, 1925, p. 65). These genera, together or separately, are listed from the Mississippian formations of Nevada (Longwell, 1928, pp. 30–31; Hewett, 1935, pp. 19–20), Utah (Gilluly, 1932, pp. 23–24; Nolan, 1935, pp. 26–27), Colorado (Girty, 1903, p. 271; Johnson, 1945, table 7), and also the Madison limestone of southeastern Idaho (Mansfield, 1927, p. 60). Easton (1944) has shown that *Triplophyllum* proper is of Onondaga age, whereas the Lower Mississippian *Triplophyllites* has a long range, through the Tournaisian and Viséan in Europe. The stratigraphic paleontology of these little corals of the Madison sea, therefore, is another problem of the southwestern Mississippian.

The forms so abundant in the Escabrosa and present in the beds with *Sp. centronatus* belong neither in *Triplophyllum* nor in *Triplophyllites*. They are closely related to certain species of the Mississippi Valley (Easton, 1944) but in many cases show a reduction and even total absence of transverse endothecal structures. Whether or not the indicated morphological difference observed in the Arizona forms also involves a different stratigraphic position (Chouteau-Burlington in the Mississippi Valley) may be questioned; but the Burlington age of the upper part of the Escabrosa limestone is supported by the presence of a blastoid, *Orophocrinus stelliformis* (Stoyanow, 1936, p. 507), at present known from widely separated localities (Santa Catalina and Veekol Mountains, a distance of over 100 miles). It is significant, also, that at the base of the Paradise formation in the Chiricahua Mountains, in the extreme southeastern part of Arizona, Chouteau-Burlington brachiopods, like *Sp. gregeri*, occur below the *Sp. centronatus* zone (Hernon, 1935, p. 658).

The Lower Mississippian "*Leptaena analoga*" is generally interpreted as a species with a larger shell than the earlier "*L. rhomboidalis*." The Escabrosa form is small (10 mm. long and 18 mm. wide). It is closer to *L. convexa* Weller and more resembles the pre-Mississippian species.

One of the outstanding characteristics of the Escabrosa is the paucity of productids. If "*Productus semireticulatus*" of Ransome's (1904, p. 50) collection from Bisbee is the Pennsylvanian *Dictyoclostus americanus* (which is quite probable because the Pennsylvanian Naco limestone rests with perfect apparent conformity on the Escabrosa limestone), that leaves only 2 species—*Linoproductus ovatus* and *D. mesialis* (Stoyanow, 1936, p. 505). In marked contrast the Redwall limestone contains 15 species, and the Lower Mis-

sissippian formations of neighboring states have 7 or 8 species, including related forms. There are 7 species in the Monte Cristo limestone of Nevada; 7 in the Stockton and Fairfield quadrangles in Utah; 7 in Colorado; and at least 8 in the Madison limestone of southeastern Idaho. On the other hand, only 1 species has been reported from the Madison limestone in the Gold Hill mining district of Utah, and 4 specifically unidentifiable forms have been listed from the Muddy Mountains of Nevada. The Lower Mississippian of New Mexico has 7 species.

Separation of the Escabrosa into zonal units may be done successfully, as it has been for the Avon series in England, on the basis of vertical and widespread areal distribution (from the Mexico border to Lake Roosevelt) of the rugose corals (especially several species of *Clinophyllum*, *Hadrophyllum*, *Dipterophyllum*, *Homalophyllites*, and *Cyathaxonia*) profusely abundant in many parts of the Escabrosa.

REDWALL LIMESTONE

The Redwall has not been adequately explored from the standpoint of paleontological stratigraphy in the Grand Canyon area, except for casual collecting on the trails cutting through inaccessible cliffs and sheer walls of the massive limestone. What is known of the Redwall fauna is based on collections gathered along the southwestern rim of the Colorado Plateau. C. E. Wooddell (1927) made a fine collection of fossils in the Jerome area (see Stoyanow, 1936, p. 512), which is now on deposit at the University of Arizona; and, more recently, Gutschick (1943) collected in the same area. Wooddell's collection contains 175 carefully studied and described species, mostly Kinderhook to Burlington in age, with Keokuk age less certainly established. The difference in the number of species compared to that of the Escabrosa is impressive. The Redwall has 10 species of brachiopods in common with the Escabrosa, 32 with the Lower Mississippian of the Mississippi Valley, 9 with the Caballero formation of New Mexico (Laudon and Bowsher, 1941), 15 with the Alamogordo member of the Lake Valley formation, and 6 each with with Argente and Dona Ana members of the same formation. On the other hand, the Escabrosa has only 7 brachiopod species in common with the Lower Mississippian of the Mississippi Valley Basin, 2 with the Caballero formation, none with the Alamogordo and Argente members of the Lake Valley formation, and 3 which occur in the Dona Ana member.

In the Lower Mississippian of the other states under discussion, the Monte Cristo limestone of Nevada contains (barring related forms) 10 brachiopod species of the Lower Mississippian of the Mississippi Valley; the Madison limestone in the Stockton and Fairfield quadrangles, Utah, has 8 such species, and in the Gold Hill mining district of the same state only 1 definitely identified species; the Madison limestone in southeastern Idaho contains 7 species of the Mississippi Valley.

Assuming equal ability of collectors and a similar preservation and frequency of fossils in different parts of the "Madison sea," it is easy to see that the depositional basin of the Redwall limestone was an exceptionally favorable habitat for the brachiopods. The latter are selected in this discussion because they are more easily identified and so cause fewer errors in stratigraphic interpretations than do other less adequately studied Lower Mississippian invertebrates of the Southwest. There are no known assemblages of well-preserved and easily determinable

crinoids, similar to those in the Dona Ana member of the Lake Valley formation of New Mexico, in other areas. The corals, as a group, have not yet been adequately studied.

Whereas many Lower Mississippian brachiopods of the Mississippi Valley occur in the strata of the southwestern sea, certain index species of the southwestern Lower Mississippian are unknown in the Mississippi Valley. This, most probably, suggests a westward migration. However, it is difficult to indicate the paths of migration and channels of communication. The Lake Valley formation of New Mexico has over fifty brachiopod species and the Redwall limestone has over thirty species which have been described from the Mississippi Valley. The other formations in the neighboring states have much less. Yet a direct communication between Redwall and Lake Valley basins does not appear plausible on present evidence. Neither the Lower Mississippian fauna of Colorado, which contains eleven brachiopod species in common with the faunas of the Mississippi Valley and New Mexico, nor the Escabrosa fauna, with seven such species, nor the geographically intermediate area of Clifton-Morenci in Arizona near the New Mexico border, with only one such species, indicates an unimpeded interchange between the faunas of the two basins. Significant also is the absence in the Lake Valley formation of such a characteristic southwestern brachiopod as *Sp. centronatus*.[5] As in the cases of the Upper Devonian and the Upper Mississippian, a communication must be sought elsewhere.

[5] The form from Michigan and Iowa described under this name by Weller (1901, p. 163, pl. 14, figs. 3–4; 1914, p. 323) is not conspecific with *Sp. centronatus* Winchell of the Southwest, which apparently was autochthonous and does not occur east of Colorado and Arizona.

EVALUATION OF THE UPPER MISSISSIPPIAN AREAS IN THE SOUTHWEST

PARADISE FORMATION, BRAZER LIMESTONE, AND WOODMAN FORMATION

The Paradise formation of Arizona (Stoyanow, 1926, p. 316; 1936, p. 508; 1942, p. 1273, pl. 5, fig. *h;* Hernon, 1935, p. 653) is of importance for interpretation of the Upper Mississippian stratigraphy of the Southwest because of its place in the sequence and because its relation to the type regions is much clearer than that of other comparable formations farther north. Over sixty species in the Paradise fauna, not counting varieties or specimens of doubtful affinity, are strictly identical with those described and illustrated by Stuart Weller (1914) and others from the Mississippi Valley and, in lesser measure, from Arkansas and Oklahoma (Moorefield-Pitkin). The clarity of interpretation increases upward from the equivalents of the St. Louis to the Chester. The areal extent of the Paradise formation is very limited; especially limited is the Chester *Archimedes* facies, the bryozoan fauna of which has been recently described by Condra and Elias (1944). It is interesting that the late Dr. Girty considered the *Archimedes* and *Pentremites* faunas, wherever abundant, to be regional types, restricted chiefly to the eastern half of the continent (Mansfield, 1927, p. 69).

Among other stratigraphic units of the Southwest with firmly established Upper Mississippian faunas, two are of special interest, namely, the Woodman formation in the Gold Hill mining district, Utah (Nolan, 1935, p. 27), and the Brazer limestone of Utah and southeastern Idaho (Mansfield, 1927, p. 63). The latter is particularly important because it includes faunas related to all facies from the Salem to the Chester in the single regional sequence.

In the Woodman formation, Nolan distinguished strata of an eastern facies, which rest unconformably on the Devonian, and strata of a western facies, which directly succeed the Madison limestone. Unfortunately, nearly all the brachiopods listed from the Woodman formation (with the exception of five species) are only related forms. Girty believed that the faunas of the Woodman formation and of the overlying Ochre Mountain limestone are not sharply distinguishable and contain assemblages too small for exact interpretation. The Upper Mississippian strata of the district are correlated with western stratigraphic units, but no comparison with the standard sections of the Mississippi Valley is available. In the Stockton-Fairfield quadrangles farther northeast (Gilluly, 1932, p. 25), the nature and relation of the collected fossils are very similar, except that *Linoproductus brazerianus* is reported from the same formation (Humbug limestone) with a form related to *Sp. centronatus*, and neither species has been found in the Upper Mississippian beds of the Gold Hill district.

Next to the Paradise, the Brazer limestone of southeastern Idaho is the most important formation for the evaluation of the southwestern Upper Mississippian. Despite Girty's statement (Mansfield, 1927, p. 63) that most of the collections taken from the Brazer ". . . appear no more related to one group than to another, or, by lacking individual character, show no close relation to any," many authentic species are illustrated in Mansfield's monograph and make a sound interpretation possible. Girty's major conclusions are: (1) the Chester fauna, though present mainly at the top of the Brazer, is not typical Chesterian because, for example, the *Archimedes* facies is absent; (2) some facies are related to stratigraphic occurrences, others are not; (3) some productids and spiriferids "are distinctly alien to the faunas of the typical Chester, indeed, they represent types not found in the Mississippi Valley above the Keokuk"; and (4) there are many forms in the part of the Brazer correlated with the Spergen which do not occur in the Spergen.

Other valuable observations by Dr. Girty need not be enumerated. Correlations with the Spergen and the Chester were made on either identical or related species. It is important to note that, because the faunas of the Brazer are considerably diffused vertically and are rather patchy laterally, collateral studies of beds farther east and west must be made before the true nature of these faunas is properly understood. There are many problems; for example, Girty regarded the so-called "alien" species of the Brazer, "*Productus*" *brazerianus*, *Martinia lata*, etc., as suggestive of older species in the Lower Mississippian of Asia, Continental Europe, and England. It seems that such forms may equally well be considered to be related to certain Pennsylvanian species of the Ural Mountains. Girty's *M. lata* bears a close resemblance to *M. semiglobosa* Tschern. (Tschernyschew, 1902, pl. 17, figs. 6–9 and 12–13), including the observed and discussed similarity to the Reticulariinae. "*P.*" *brazerianus* Girty (in Butler *et al.*, 1920, p. 643, pl. 53, figs. 1–2*a*), with its small beak, also seems rather to resemble the less inflated but wide-hinged forms of the Uralian "*P. cora*" (Tschernyschew, 1902, pl. 35, fig. 1; pl. 54, figs. 1–5) rather than *Gigantella gigantea* (Martin), which has unusually large and broad umbonal region (Davidson, 1857, pls. 39 and 40). The relation of the Brazer species to "*P. cora*" and "*P.*" *giganteus* was discussed at length by Girty himself. It is

quite probable that this species is autochthonous. *Spirifer haydenianus* Girty (in Mansfield, 1927, p. 416, pl. 24, figs. 18–21), which Girty compared to *S. striatus* (Martin) of the European Mississippian (Davidson, 1857, pl. 2, figs. 12–21; pl. 3, figs. 2–6) also does not seem to be related to the latter species any more than to "*Sp. striatus*" from the Pennsylvanian of the Urals (Tschernyschew, 1902, pl. 40, figs. 5*a–c*).

PALEOGEOGRAPHIC RELATIONS AND PROBLEMS

Granting that the widespread dispersal of a marine fauna takes considerably less time than any evolutionary changes that may be incurred during the migration, a satisfactory correlation of strata containing faunas with identical or closely related species in different, and even very remote, regions is justified. However, the identity of remote faunas requires an explanation of their paleogeographic relationship. The paleogeographer may freely pencil in seas and continents, but, as the geographic distance decreases, his responsibility for the correctness of his interpretations increases in geometrical progression.

Any regional paleogeographic interpretation for a given unit of time must take account of factors inherited from the previous periods and the regional changes of previous times. Southwest and south of the Colorado Plateau in Arizona the Paleozoic strata exposed in a great many outcrops invariably consist of a uniform sequence of limestone beds, with the exception of certain areas in the vicinity of the ancient pre-Cambrian upland in central Arizona. The thin conglomerate at the base of the Pennsylvanian, present everywhere except in extreme southeastern Arizona, and the weak, often gypsiferous and shaly, members of the Permian (Stoyanow, 1942), long remained unnoticed, probably because of their insignificant volume in the dominating mass of Paleozoic limestones. The remarkable uniformity and the apparently perfect conformity of the strata of five different Paleozoic periods (the Middle and Upper Ordovician, Silurian, Lower and Middle Devonian, beds are absent in all sections; the Lower Ordovician and Upper Mississippian strata are present only in limited areas near the New Mexico border) have not been obscured either by the major time intervals or by the post-Paleozoic orogenic movements. The widespread Upper Cambrian–Upper Devonian contact is especially impressive.

The relative scarcity of clastic materials in the southeastern half of the state, the absence of marginal belts of clastic rocks, and the overwhelming predominance of limestone in the Paleozoic strata all suggest that no major Paleozoic geosynclines have ever crossed Arizona and that the ancient schistose-granitic platform, "Mazatzal Land" of the writer (Stoyanow, 1936, 1942), remained essentially undisturbed and an area of comparatively low relief throughout the Paleozoic.

Nolan (1928, p. 154; 1935, p. 24; 1943, p. 153) has pointed out the principal characteristics of the Mississippian Cordilleran geosyncline in Nevada and Utah, which in early Mississippian time had a northeasterly trend approximately parallel to a line from the Death Valley region in California to Gold Hill in Utah. The geosyncline later spread farther westward. It is reasonable to suppose that the Redwall basin connected to the northwest with the geosyncline approximately in the region of strongly folded mountains in southwestern Utah.

It is more difficult to demonstrate

communication channels for the Escabrosa and the Paradise seas. There is little in common in the faunal lists of the Escabrosa and the Lake Valley of New Mexico, and there is slight probability of a direct connection between the two basins. There remain the alternatives of northwestern and southeastern communications. It is possible that there were impeded and brief connecting channels between the Escabrosa and the Redwall basins either directly across the barrier of the Mazatzal quartzite in central Arizona or through an unknown area now under the younger beds of the plateau. The impoverished brachiopod fauna of the Escabrosa may have resulted from such conditions. An alternate or concurrent channel may have passed through Mexico. There is very strong evidence of a Paleozoic trough and a westward portal in northern Sonora (Stoyanow, 1942, pp. 1263, 1272, 1279). I have some Lower Mississippian fossils collected by my Mexican colleagues from the limestone beds near Bizani in the Altar Valley which suggest an Osage age, and recently Cooper and Arellano (1946, p. 606) reported the presence of Lower and Middle Mississippian in the same area. However, judgment on the relation of the Bizani fauna to the Escabrosa (compare Stoyanow, 1942, p. 1272) would be premature.

Concerning the possibility of a southern outlet of the Cordilleran geosyncline of late Mississippian time in the Great Basin, Nolan (1943, p. 153) states: "The later Mississippian sea extended considerably farther westward into Nevada, to the Inyo Mountains, California. Whether it was joined with the sea of the same age in central and northern California by a passage to the north or to the south is not yet known." I have called attention in two articles to the absence of Paleozoic sediments in southwestern Arizona, where the only exposed bedrock is pre-Cambrian schist, granite, and subrecent volcanics, and have also pointed out the known localities where Paleozoic fossils have been redeposited in post-Paleozoic, often poorly consolidated, strata (Stoyanow, 1942, pp. 1272, 1278–1279). I referred to the extreme southwestern part of Arizona as "Altar headland of Mazatzal Land" on the assumption that the schistose-granitic basement extends into Sonora. In my opinion the geological evidence of the presence and stability of the southwestern headland is rather strong. It appears that in southwestern Arizona there is a virgation of the schistose and granitic ranges nearly around a center of resistance, in striking contrast with the monotonous northwestern trend of the ranges in southeastern and central Arizona. This virgation is well indicated in the Geologic Map of Arizona prepared by the Arizona Bureau of Mines in co-operation with the United States Geological Survey, and I have attempted to illustrate it diagrammatically (Stoyanow, 1942, p. 1257, fig. 1).

There are no undoubted Paleozoic deposits in west-central Arizona south of the Harquahala Mountains (Darton, 1925, pp. 215–223; Stoyanow, 1942, p. 1278), and all supposed evidence to the contrary deals with the finds of redeposited fossils on the periphery of the discussed area in southwestern Arizona. Recently Cooper and Arellano (1946, p. 608) questioned the Altar headland (they have had the advantage of doing field work in Sonora, where I have never been) and point out the presence of metamorphic rocks and granitic intrusions. They state that, although they are unable to determine the age of these rocks, their observations and published papers on the Paleozoic of Sonora give no support to the concept of such a

"headland." The occurrence of intrusive rocks in the Altar-Magdalena region of Sonora, especially where such rocks have intruded and mineralized limestone is fairly well known to the mining geologists of Arizona. Cooper and Arellano fail to cite any reference to the area between the Altar-Magdalena region and southwestern Arizona. Does the schistose-granitic platform stop abruptly at the international border, and, if not, how far and in what direction does it extend into Sonora? Information that I have from traveling geologists suggests that the westward extent is considerable; whether similar rocks extend southeastward neither Cooper and Arellano nor I know; and my theory, based on the difference of Middle Cambrian trilobite faunas found in southeastern Arizona and the Altar-Magdalena region, respectively, seems to be satisfactorily grounded. It should also be mentioned that at present the evidence in favor of the existence of Paleozoic seaways in southwestern Arizona is very insufficient. According to Russell Wheeler (1936), the Cambrian Bright Angel shale extends from the Grand Canyon area to the headwaters of the East Verde River, much farther south than I had supposed (Stoyanow, 1942, p. 1262, pl. 5, fig. *a*). A couple of years ago E. D. Wilson, geologist of the Arizona Bureau of Mines brought to Tucson a slab from the Harquahala Mountains in which I identified Cambrian trilobites. In the same area and in a redeposited condition 40 miles to the west, McKee (1947, p. 282) collected trilobites with *Glossopleura* (identified by Cooper) in the assemblage. Citing the finds of *Glossopleura* in Sonora (Stoyanow, 1942; Cooper and Arellano, 1946), McKee concluded: "Thus, it seems definite that in early Middle Cambrian time a seaway was continuous from western Mexico through Arizona into the Grand Canyon area." Inasmuch as McKee (1947, p. 288) believed that the lithological similarity between the Cambrian of Harquahala and the Grand Canyon indicated a close relation between these areas, it seems more probable that the Harquahala trilobites belong in the Cambrian Basin of the Grand Canyon area, there being no evidence of Cambrian strata on the schistose-granitic platform of southwestern Arizona. There have been no other attempts to postulate Paleozoic seas in that region of Arizona.

Bearing in mind the above discussion of the general paleogeographic setting in early Paleozoic time and also taking cognizance of the absence of the Ordovician and Silurian in Arizona (excepting the presence of the Beekmantown in the Clifton-Morenci quadrangle and in the Dos Cabezas Mountains along the New Mexico border) and northern Sonora, it is easier to interpret the nature of late Paleozoic rocks north of the international border and south of it in the Magdalena-Altar region of Sonora. All evidence of the Paradise fauna is lost within 60–80 miles west and northwest of the type locality. At Bisbee, in the Escabrosa Ridge and in the Naco Hills, an important break is observed between the Lower Mississippian and the Pennsylvanian. The same relationships, with or without a dividing conglomerate, are present in all border mountains to the west—the Huachuca, the Whetstone, the Empire, the Santa Rita, and the Patagonia Mountains. There was no depositional basin along the international border in Paradise time.

Hernon (1935, p. 659) thought that there might have been an eastern way of communication between the Paradise Basin and the eastern sources of the Upper Mississippian fauna across New

Mexico, but the more recent work of Laudon and Bowsher (1941) shows the absence of faunas younger than those of the lower Burlington formation of the Mississippi Valley in the Mississippian sections of that state. In the United States there are no known Upper Mississippian strata between the Paradise Basin and the area with the Helms formation in western Texas (Nelson, 1940, p. 165). Even the western Texas occurrence is in doubt because Condra and Elias (1944, p. 6) concluded, after examining the United States Geological Survey collection of *Archimedes* from the Helms area, that some of the specimens indicate Lower Pennsylvanian rather than Chester age.

Therefore, the finding of some part of the Paradise fauna and formation in the El Tigre area in Sonora and south of Douglas, Arizona, by Imlay (1939, pp. 1731–1732) is of particular interest. Cooper, who examined Imlay's collection, correlated the strata at El Tigre with the Ste. Genevieve formation of the Mississippi Valley and (probably) with the lower part of the Paradise formation. I know of no evidence that there was a direct eastward communication with the Mississippi Valley Basin south of the international border through Chihuahua and Coahuila. On the other hand, Cooper and Arellano (1946, p. 610) believe that they have located Upper Mississippian strata in the Magdalena-Altar region near Bizani; as is the case with the El Tigre area, the strata studied are correlated with the Ste. Genevieve of the Mississippi Valley and also with the lower part of the Paradise formation. This evidence, meager as it may seem, is the only indication of the regional distribution of the Paradise fauna in the Southwest. It is significant that the direction indicated by these finds *is to the west* and considerably southwest from the belts with the Mississippian strata in Arizona.

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MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY PROBLEMS IN THE ROCKY MOUNTAIN REGION[1]

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ABSTRACT

A variety of paleontologic and stratigraphic problems are presented by rocks near the Mississippian-Pennsylvanian boundary in the central and northern Rocky Mountains. Stratigraphic sections of these rocks show diverse interpretations of fundamental concepts of stratigraphy and paleontology. In many places where Upper Mississippian rocks directly underlie Pennsylvanian rocks it is difficult to determine the precise location of the boundary between these units. Formations that straddle the boundary are very useful and satisfactory over large areas. Most geologists use various types of lithologic criteria to distinguish formations, but some appear to rely mainly on faunal data, unconformities, or attempts to trace prominent beds. More uniformity in criteria than now exists for the delimitation of formations is desirable. Surface and subsurface formations should conform to the same definition. Critical paleontologic studies of several common species and genera, if based on a large number of specimens, might help solve the boundary problem. More correlations based on several lines of paleontologic evidence and less reliance on a few index fossils would also help. Larger and more varied collections of well-preserved fossils stratigraphically located are needed from critical areas. Additional stratigraphic work in this region should be of a detailed nature and should preferably be done in connection with detailed mapping. Ecologic and paleogeographic factors merit more attention. The age significance of unconformities has perhaps been overestimated generally.

INTRODUCTION

As in many other parts of the United States, the Mississippian and Pennsylvanian rocks of the Rocky Mountain region present many unsolved problems. These problems relate to all stratigraphic zones from the base of the Mississippian to the top of the Pennsylvanian. A group of problems that involve beds at or near the Mississippian-Pennsylvanian boundary are especially interesting because they not only show places at which the geological data are sadly deficient but also involve interpretations and differences in viewpoints on fundamental principles of paleontology and stratigraphy.

All students of Carboniferous problems, especially those who have themselves worked in the Rocky Mountains, will agree that much geologic work needs to be done there. The type of work most needed, in the writer's opinion, is not, however, reconnaissance work but detailed work, whereby the investigator becomes well informed on a single small problem or spends considerable time on a large problem. There is, however, also room for broadly interpretive work. Considering the vast area of the Rocky Mountains underlain by Carboniferous rocks and the difficulty of access of many of the exposures, a very creditable amount of knowledge of the stratigraphy and paleontology has existed for a long time; but not all of it is published, and much that is published is in papers concerned also with general and economic geology; with which papers many stratigraphers appear to be unfamiliar. This knowledge must be considered by anyone starting work in the Rocky Mountains.

Problems in the Rocky Mountain Carboniferous (not all of which will be solved or even reviewed in this paper!) range from the need for more and better fossils, carefully collected with respect to their geographic locations and stratigraphic horizons, to the need for reviews, and perhaps reappraisals, of some of the fundamental hypotheses and definitions used in stratigraphy and paleontology.

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Among these last-named are such things as definitions of various rock and time units and the applications of these definitions in the field; hypotheses of, and factors in, the correlation of strata; and theories of species definition in paleontology. Despite the two hundred and thirty or more years of the existence of the science of stratigraphy and stratigraphic paleontology, many disagreements exist in the application, if not in the definition, of many of the fundamental or near-fundamental concepts upon which the daily work of the stratigrapher and stratigraphic paleontologist is based.

Whether one considers the Mississippian-Pennsylvanian boundary a systemic, subsystemic, or series boundary depends on the definitions of a system, a subsystem, and a series to which one subscribes and on the applications (or interpretations) of these definitions in particular regions and with particular sequences of rocks; also involved are the uses or underlying purposes that one has in mind for each of the units, the general usage throughout the world, the degree of reliance and degree of fineness of intercontinental correlations of the particular units of rocks under consideration, and the breadth of experience one has with the rocks involved. All these are variable, and there is certainly adequate room for justified disagreements in the weights and interpretations given each of the above factors and for disagreement in the rank assigned to the units called "Mississippian" and "Pennsylvanian." A definite agreement is not necessary, and it would be outside the scope of this paper to present arguments for or against any specific conclusion. The writer considers that the Mississippian-Pennsylvanian boundary is an important boundary in the United States (more so in some regions than in others) and believes it to be an important time and time-rock boundary, as distinct from a lithologic boundary. It may (and does) happen to coincide with distinct lithologic changes in some places but not with important lithologic changes in others. It coincides with an unconformity in some regions and not with a recognizable unconformity in others. It is a practical boundary for mapping in some places, and in others it is not. Nevertheless, this boundary is one of the more important ones in the United States.

POSITION OF MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY

All who are familiar with the general geology of the central and northern Rocky Mountains know that, broadly speaking, the Mississippian rocks there constitute a sequence mainly of limestones, whereas the Pennsylvanian rocks constitute a dominantly sandstone or "quartzite" sequence. Between the dominantly limestone sequence of the Mississippian and the dominantly sandstone sequence of the Pennsylvanian there lies a series of thin and in many places alternating beds of sandstones, shales, thin limestones, cherts, and other kinds of rock. In many places this series of rocks contains red or purple beds, material from which stains associated beds and at many exposures the whole series has a reddish tinge. In many places the Mississippian-Pennsylvanian boundary is within this series of rocks, some of the beds being Mississippian and others Pennsylvanian. In other places, however, the Mississippian-Pennsylvanian boundary, as determined by fossils, appears to coincide with a lithologic boundary. The Mississippian-Pennsylvanian boundary is placed within a series of alternating thin-bedded rocks—a nonresistant series—not only in the area here discussed but

in a far wider area in the western part of the United States.

FORMATIONS INVOLVED

Early practice.—The variable beds between the Mississippian limestones and the Pennsylvanian sandstones or quartzites have, in the area under discussion, been placed in different formations in different parts of the area. In western and central Montana and in northwestern Wyoming they were generally assigned to the lower part of the Quadrant formation and widely, but not universally, considered Mississippian in age. In west-central and central-northern Wyoming and in parts of Montana contiguous to northern Wyoming, they were placed in the Amsden formation, which has from 1906 (Darton, 1906, p. 5), two years after the time of the proposal of the name "Amsden" for the beds, been generally considered to be of both Mississippian and Pennsylvanian age. In southeastern and eastern Idaho and contiguous parts of western Wyoming and Utah, the lower beds of the sequence were for a long time placed in the upper part of the Brazer limestone and the upper beds in the lower part of the Wells formation. In mapping begun in 1931 in the Afton quadrangle, southeastern Idaho and southern Wyoming, but as yet unpublished, W. W. Rubey and the writer grouped the beds together in a single mapping unit, to which a field name has been applied pending decision as to which of the available names to use. In north-central Utah the beds were put in the Morgan formation, which was considered by its namer, Eliot Blackwelder (1910, p. 530), to be Pennsylvanian in age, but which may contain Mississippian beds in its lower part. The writer has collected Pennsylvanian fossils from the type section and other exposures of the Morgan, and Mississippian fossils from beds that might be considered Lower Morgan. The name "Morgan" has been extended into the Cottonwood–American Fork region of the Wasatch Mountains and to other areas in this part of the Wasatch Mountains and has also been used at several places in the Uinta Mountains.

In central-western Utah, the nonresistant unit of alternating shales, limestones, and sandstones in which the Mississippian-Pennsylvanian boundary occurs has little red material. At this place the unit was called the Manning Canyon shale by Gilluly (1932, pp. 31–34). The name Manning Canyon has been used also for units of approximately the same age in eastern Nevada and at other places in central Utah, including at least one area in the Wasatch Mountains, near Provo (Baker, 1947).

The above paragraphs give the general usage as of about 1930 (fig. 1). This shows that in most places the Mississippian-Pennsylvanian boundary was frankly acknowledged not to be a practical mapping (i.e., formational) boundary but to lie within a formation. Exceptions to this were found, however, in the southeastern Idaho area, where attempts (abandoned by W. W. Rubey and the writer) were made to map the Mississippian-Pennsylvanian contact as the Brazer-Wells contact and, to a degree, in the area of the typical Morgan formation, where all of the Morgan was considered to be of Pennsylvanian age.

Recent work.—Much work has been done in the central and northern Rocky Mountains since 1930. The United States Geological Survey has had many field parties working in various parts of the region. Renewed interest in stratigraphic problems has been shown by some of the state geological organizations and especially by geologists on the faculties of col-

leges and universities in the area. Very important contributions have been made by the faculties and student bodies of the many summer camps maintained by mid-western and eastern universities in different parts of the Rocky Mountains.

some of the identifications are as yet provisional. Most of the sections measured by Geological Survey parties have been published. Unfortunately, wartime and other duties have prevented the writer from compiling and publishing many of

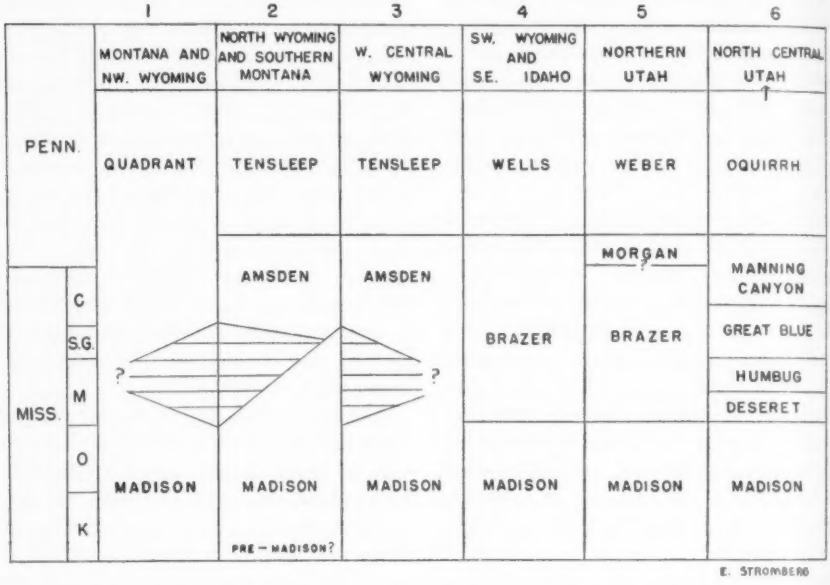

FIG. 1.—Correlation chart showing widespread usage as of about 1930. The stratigraphic usage shown for several of the areas on the chart is still the preferred and most satisfactory, but it has changed in other areas. The diagonal lines at the base and top of the cross-lined areas represent an attempt to show that both the top of the Madison limestone and the base of the Amsden formation probably are of different ages in different places, or are thought to be by different geologists. The abbreviations are for the well-known Mississippi Valley subdivisions of the Mississippian.

The writer has aided nearly every United States Geological Survey party that has worked in this area since 1930 with its problems in Carboniferous rocks and, in addition, while engaged in stratigraphic projects of his own, has measured many sections in areas not worked in detail by the Survey mapping parties. Fossils have been systematically, though not always adequately, collected from nearly all these sections, and most of these have been identified, although the sections that he has measured independently and from studying carefully all the collections of fossils in his hands.

SELECTED STRATIGRAPHIC SECTIONS

The total stratigraphic work done on the Mississippian-Pennsylvanian boundary problem by all the geologists who have worked in this region is so great and the number of stratigraphic sections is so large that only a small proportion of them can be discussed in this paper. Con-

sequently, a few sections have been selected to show the trends in each of several areas. It is hoped that these sections will reveal general tendencies in procedure that can be evaluated later and will show some of the specific deficiencies of knowledge, disagreements in philosophies, and other problems that exist in connection with the stratigraphy and paleontology of the Mississippian-Pennsylvanian boundary in the Rocky Mountains. The sections given here were selected because they are more or less typical of the areas or because they show fossil occurrences, lithologic features, or terminology that the writer believes are of interest. The writer has personally visited the area of each section cited from the various publications. Several of the sections have been examined in the field with the men who measured them.

SECTION IN THE BIG SNOWY MOUNTAINS CENTRAL MONTANA

The section in the Big Snowy Mountains of central Montana (sec. 1, fig. 2) is condensed from one published by Scott in 1935 (p. 1024). It is given to indicate changes in usage that have gained wide acceptance in a part of the area where the nonresistant alternating beds were for a long time placed in the Quadrant formation. The locality is "on north flank of Big Snowy Mountains, sec. 6, T. 12 N., R. 20 E."

Reeves in 1931 (p. 140) recognized four units in the Quadrant formation which he described as follows: (1) an upper thin-bedded fossiliferous limestone interbedded with red shale, 100–200 feet thick; (2) a unit of red, brown, and black shales and cross-bedded sandstones, 300–400 feet thick; (3) a 500-foot unit of variegated calcareous shale, with a few thin limestones and including a predominantly green shale near the middle; (4) a basal unit of yellow sandstone, sandy shale, and gypsum, 150–200 feet thick. Girty, who examined the fossil collections made by Reeves, identified fossils from the middle and lower part of the upper limestone unit that, though not definitely diagnostic, were considered to be upper Mississippian in age (either Ste. Genevieve or Chester or both), but he considered a collection from near the top of this limestone unit at another place to be clearly Pottsville (Pennsylvanian). The writer has collections from this limestone, but he has not yet been able to study them or to re-examine Girty's collections.

The main sandstone or quartzite, to which the name "Quadrant" is now generally restricted and which is probably younger than any of the beds in Reeves's section, is represented only by a few outliers, if at all, in the Big Snowy area, but considerable thicknesses of this sandstone occur in other parts of Montana. In many places Jurassic beds rest on Reeves's upper thin-bedded limestone of the Quadrant formation. In 1935, Scott described some fifteen or more stratigraphic sections in Montana, including the one here cited in the Big Snowy Mountains. Like Reeves, he divided the Quadrant into four units in the Big Snowies, but his units did not coincide precisely with those of Reeves. For his two lower units he brought in the names Kibbey and Otter, names used by Weed for members of the Quadrant in the Little Belt Mountains. To a unit composed in large part of "black petroliferous shales and sandstones" immediately below the upper limestone unit of Reeves, he gave the name Heath formation. For the upper limestone unit he brought in Darton's (1904, p. 396) Amsden from central-northern Wyoming. Scott considered the Kibbey, Otter, and

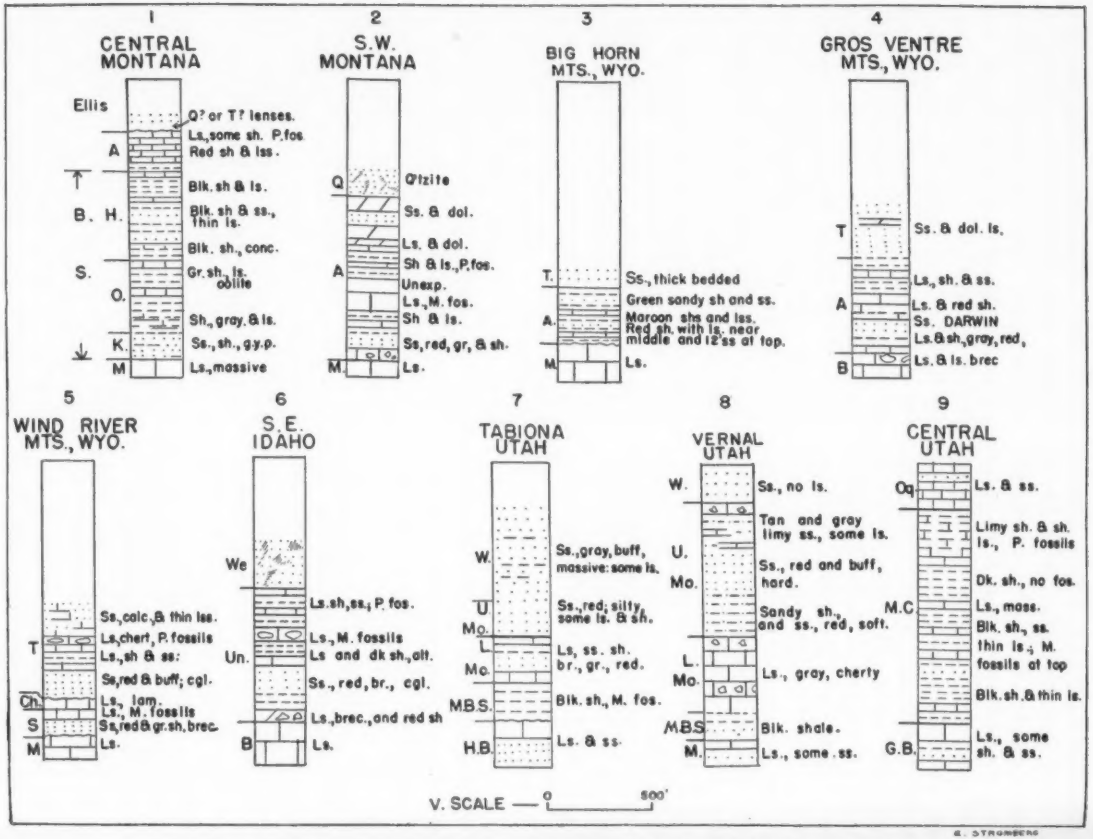

FIG. 2.—Selected stratigraphic sections crossing the Mississippian–Pennsylvanian boundary

Heath to be of formational rank and to belong to a group to which he applied the name Big Snowy group. Evidence from several classes of fossils published by different investigators has confirmed the Upper Mississippian age of the Big Snowy group and has suggested correlations of specific units with other units in the Mid-Continent region. The age of the Amsden of Scott of this region is not, however, firmly established. As stated earlier, Girty identified some of the faunules from it as upper Mississippian and others as Pennsylvanian. Scott in 1935 (p. 1032) considered the unit that he called Amsden in the Big Snowy Mountains to be of Mississippian age. Later in 1945 (1945*a*, p. 1195; 1945*b*, p. 1196), he assigned the Amsden of central Montana to the Pennsylvanian not only because, presumably, of a big overlap at its base that he had recognized in 1935 but also because, mainly, of the presence of certain species of *Millerella* in it. Other microfossils occur in the Amsden, but those so far identified are not definitely diagnostic. Though *Millerella* was for a time thought to be only of lowest Pennsylvanian age, it now is known to have a long range, which includes Mississippian as well as late Pennsylvanian, and some paleontologists maintain that species of *Millerella* are not yet safe zone markers. Perry and Sloss in 1943 (p. 1293) also described an overlap at the base of the Amsden, but they considered the Amsden to be both upper Mississippian and lower Pennsylvanian. The overlap, according to them, would then have occurred in upper Mississippian time. Thom and others have mentioned some evidence of physical unconformity at the base of the Amsden. Perry and Sloss also describe an unconformity at the base of the Big Snowy group, with sandstones of the Kibbey formation filling channels and solution cavities some 300 feet below the top of the Madison limestone. On the other hand, Scott (1935), Perry (1937), Pardee (1937), and others suggest an unconformity above the Amsden formation in Montana.

The three units that make up Scott's Big Snowy group have been mapped as formations in several places in Montana and have been recognized in subsurface as far east as the Dakotas and northward into Canada. The variations in thickness and paleogeography of these units are shown on maps by Perry and Sloss (1943). The Charles formation, proposed by Seager as part of the Big Snowy group below the Kibbey, has not yet gained wide recognition in surface work. The validity of Scott's use of the Kibbey, Heath, and Otter as formations would seem to the writer to be established either on the surface or in subsurface in those areas where each has sufficient thickness and distinction to qualify it as a mappable lithologic unit on the scales ordinarily used for topographic quadrangle

FIG. 2.—Selected stratigraphic sections crossing the Mississippian-Pennsylvanian boundary

Explanation of Figure 2

The sections of figure 2 were selected to show interesting fossil occurrences, lithologic features, and stratigraphic terminology. Many of them are condensed in order that they may be shown together on one figure. The references are given in connection with the discussions of the sections on pp. 331–340. Only small parts of the lowest and uppermost formations in each of the sections are shown.

The following are the names for which the abbreviations in the respective sections stand: *1: B.S.*, Big Snowy group; *Q?*, Quadrant?; *T?*, Tensleep?; *A*, Amsden; *H*, Heath; *O*, Otter; *K*, Kibbey; *M*, Madison. *2: Q*, Quadrant; *A*, Amsden; *M*, Madison. *3: T*, Tensleep; *A*, Amsden; *M*, Madison. *4: T*, Tensleep; *A*, Amsden; *B*, Brazer. *5: T*, Tensleep; *Ch*, Chester; *S*, Sacajawea; *M*, Madison. *6: We*, Wells; *Un*, unnamed beds; *B*, Brazer. *7: W*, Weber; *U. Mo.*, Upper Morgan; *L. Mo*, Lower Morgan; *M.B.S.*, Mississippian black shale; *H.B.*, Humbug. *8: W.*, Weber; *U. Mo.*, Upper Morgan; *L. Mo.*, Lower Morgan; *M.B.S.*, Mississippian black shale; *M*, Mississippian. *9: Oq.*, Oquirrh; *M.C.*, Manning Canyon; *G.B.*, Great Blue.

work in the area in which it occurs. In other places these units would, if recognizable, be reduced to member or bed status. In this last alternative the question arises as to what formation they would be referred as members—an enlarged Amsden formation, a Big Snowy formation, or an entirely new formation. Terminology used in sections measured by Gardner, Hendricks, Hadley, and Rogers (1945) of the United States Geological Survey, suggests that the Kibbey, Otter, and Heath lose their identity, at least as formations, in short distances. This seems so because in some areas that are near the stratigraphic sections in which these authors recognize Scott's formations—Kibbey, Otter, and Heath—the same authors place all the beds between the Madison and the Quadrant in the Amsden. The Amsden as thus used may or may not contain equivalents of the Kibbey, Otter, and Heath. Some would maintain that these three units have pinched out and been overlapped by the Amsden. Another interpretation would be that the Kibbey, Otter, and Heath in some areas contain lenticular beds that change laterally so that the formations soon lose their identity in these areas. The apparent increase in thickness of the Amsden in places where the formations of the Big Snowy group are not recognizable and the Amsden is the only formation between the Madison and the Quadrant would favor the last interpretation. Unfortunately, fossils so far obtained are inadequate to solve this problem.

SECTION IN SOUTHWESTERN MONTANA

Section 2 of figure 2 is a section taken from those published by Gardner, Hendricks, Hadley, Rogers, and Sloss (1946), mentioned above. The section is condensed for graphic representation. The location is near Sappington, southwestern Montana, in Sappington Canyon, in Section 25, T. 1 N., R. 2 W., about 14 miles southwest of Three Forks and about 35–40 miles southwest of the Big Snowy Mountains. The formations shown are the Madison, the Amsden, and the Quadrant. A limestone breccia at the base of the Amsden formation suggests an unconformity. L. L. Sloss has identified Mississippian fossils, including *Diaphragmus*, from the lowest thick limestone unit shown in the Amsden of the section and Pennsylvanian fossils from a series of siltstones, 50–100 feet above the top of the limestone that bears Mississippian fossils. The top of the Amsden formation is here drawn at the top of the nonresistant beds, and a considerable thickness of alternating sandstones and dolomites is included in the Amsden. The uniformity in lithology of the Quadrant seems to have been the deciding factor in delineating it as a formation and in distinguishing it from the Amsden, which is recognized by its heterogeneity in composition and nonresistant character.

SECTION IN THE BIG HORN MOUNTAINS, WYOMING

Section 3 of figure 2, from the Big Horn Mountains, is condensed from one measured by Darton (1906, p. 5) in the canyon of Little Tongue River, Dayton quadrangle, Wyoming. This section was selected because it is only about 6 miles from the type locality of the Amsden formation. The type locality is given by Darton (1904, p. 396), who defined the formations as the Amsden Branch of Tongue River, about 5 miles southwest of Dayton, in the Dayton quadrangle, Wyoming. As shown in the figure, some of the thicknesses are slightly exaggerated. The total thickness of the Amsden is 190 feet. The terminology, which is that of

Darton, is widely used in this region at the present time. Judging from C. C. Branson's (1939, pp. 1202–1213) usage in sections in the Big Horn Mountains, probably some of the lower beds of Darton's section, possibly those up to the base of the 12-foot sandstone, would be included by him in his Sacajawea, or in other beds referred by him to the Mississippian. The typical area of Branson's Sacajawea formation, discussed later in this paper, is in the Wind River Mountains. To the writer's knowledge, Branson has not cited faunal evidence for extending it into the Big Horn Mountains, so presumably the extension was based mainly on lithology. No specific lithologic features, however, have been given to explain the extension or to furnish criteria for the lithologic differentiation of the Sacajawea from overlying beds.

In the Big Horn Mountains, the Amsden is a variable formation, both in thickness and in lithology. Because of the thickening and thinning of many beds in short distances, one suspects that at some stratigraphic zones they are lenticular. In several places the basal bed is a sandstone, which may attain a thickness of as much as 100 feet or more, but sandstones occur at several stratigraphic positions in the Amsden of most areas. In a section measured by the writer in 1920, along Little Goose Creek, about 25 miles southeast of the type locality, a thin-bedded sandy limestone that is dense to finely crystalline and has a purplish cast was considered the basal bed of the Amsden.

The contact with the underlying Madison limestone in this region in many places is irregular, and shales from the Amsden fill depressions some of which are probably sinkholes in the Madison.

The writer knows of no fossils from the type locality of the Amsden, but in print fossils have been reported from the Amsden of the Big Horn Mountains from several localities. The writer has collected them from other localities in the Big Horns. The presence of fossils of probable Carboniferous age from the upper part of the Amsden was mentioned by Darton (1904) in his original description of the formation. Pennsylvanian fossils from the Amsden have since been listed in many United States Geological Survey papers and in other publications. Some of these fossil lists were brought together by C. C. Branson in 1939. Fossils are not abundant in the lower part of the Amsden of the Big Horn Mountains; but, in 1906, Darton (p. 5) mentioned the occurrence of a coral identified by Girty as *Menophyllum excavatum* Girty and fragments of a *Spirifer* and a "Zaphrentis" from a limestone bed in the lower part of the Amsden near Soldier Creek, some 15–20 miles southwest of the type locality. Girty believed that these suggested Mississippian age for the lower Amsden; and the Amsden in this general area has for a long time been generally considered to contain both Mississippian and Pennsylvanian beds. The writer does not consider these fossils of themselves adequate to establish a Mississippian age for the lower part of the Amsden; but the absence of definite Pennsylvanian fossils near the base of the Amsden in the Big Horn Mountains and the presence of Mississippian fossils in the alternating series of beds between the Madison limestone and the Quadrant (Tensleep) formation north and west of the Big Horns in Montana and south and west of them in central Wyoming strengthen considerably the meager fossil evidence for a Mississippian age of the lower Amsden in the Big Horns. If definite stratigraphic tracing could show that the lowest beds of the Amsden of the Big Horns were

younger than the youngest near-by beds with Mississippian fossils, it would be an argument for the absence of Mississippian beds in the Big Horn Mountains, but this does not appear to be possible because of the areas of younger rocks between the mountain ranges. From time to time, verbal reports are made of the discovery of Pennsylvanian fossils in the basal Amsden of the Big Horns, but the writer does not know of any published record. Collections from the Amsden made in conjunction with field work in the Big Horns and mountains west of the Big Horn Basin by W. G. Pierce and D. A. Andrews and the writer have not yet been carefully studied.

In the Big Horn Mountains the sandstone near the base of the Amsden has been identified by some geologists as the Darwin sandstone member, whose type locality is in the Gros Ventre Mountains. This identification appears to be based on lithologic similarity and similar position in the stratigraphic succession. Some geologists would place the Mississippian-Pennsylvanian boundary at the base of the Darwin sandstone, not only in the Gros Ventres, but in other areas where they believe the Darwin can be recognized. Such an interpretation would not give a boundary closely tied to faunal data, as diagnostic fossils are not known from beds near this boundary. The practical advantages in mapping a unit boundary at the base of a prominent sandstone where that sandstone can be definitely identified are easily understood; but to assume without faunal data that such a boundary is a period or epoch boundary seems to the writer to be unjustified, even though an unconformity might be present. To use the base of the Darwin sandstone unit as the base of the Amsden, even if that sandstone can be definitely identified from section to section, would add still another type of lithologic criteria to those used elsewhere for the base of the Amsden, as there are several feet of nonresistant alternating shaly beds below the Darwin, or so-called "Darwin," at many places. The Amsden in many different places in the Big Horn Mountains and Big Horn Basin and at other places in Wyoming has been described and mapped by many geologists. Most geologists have considered it in part Mississippian and in part Pennsylvanian, but in local areas it has been referred entirely to the Pennsylvanian, and in a few areas, notably in the Wind River Mountains, it has been referred by a few geologists entirely to the Mississippian. Those who have placed the Amsden wholly in either the Mississippian or the Pennsylvanian have not cited definite fossil evidence from critical beds.

SECTION IN THE GROS VENTRE MOUNTAINS, WYOMING

The section selected from the Gros Ventre area (sec. 4 in fig. 2) was measured by Wanless and Bachrach and published in 1947 by Helen L. Foster (p. 1557). The locality is north of Sheep Creek in the N.E. $\frac{1}{4}$, Section 10, T. 42 N., R. 115 W., Teton County, Wyoming. This locality is near the type area of the Darwin sandstone. Miss Foster designates the beds above the Darwin as upper Amsden; those below it as lower Amsden. The Darwin sandstone in this section is given as 97 feet thick, but its thickness varies in the surrounding region. The Amsden formation was examined briefly by the writer last summer at one locality in the Gros Ventres. The beds below the Darwin, in the lower part of the Amsden, consist of red shales, gray, pink, and lavender fine-grained limestones, and beds of chert. No fossil names were listed by Miss Foster, but she states that her "lower Amsden" contains fossils resembling both Mississip-

pian and Pennsylvanian types. She believes that the Mississippian-Pennsylvanian boundary is near the base of the Darwin. In connection with studies in this area by Eliot Blackwelder, C. W. Tomlinson, and other geologists of the United States Geological Survey in 1911 and in near-by areas in subsequent years, Dr. G. H. Girty examined many collections of fossils from beds referred to the Amsden. Lists from two different stratigraphic zones are published in Blackwelder's paper (1913, p. 176). The list for the uppermost zone, which is said to be from a thin group of limestone beds a little below the middle of the formation, shows the zone clearly to be Pennsylvanian. The fossils from a zone 60 feet lower are not so diagnostic but appear to the writer to be also Pennsylvanian. Girty, however, reserves the possibility that they may be Mississippian. There has not been an opportunity for the writer to re-examine the actual collections or to study Blackwelder's field notes. Neither collection is located stratigraphically with respect to the Darwin sandstone, but it is probable that both came from beds above it. This cannot, however, be definitely stated. The United States Geological Survey has had a field party working in the Gros Ventres during the past season, and several universities have had students and faculty members working there in recent summers. It is to be hoped that the examination of fossils obtained by these investigators will soon supply some definite faunal data on the age of the Darwin sandstone member of the Amsden.

SECTION IN THE WIND RIVER MOUNTAINS, WYOMING

Section 5, figure 2, shows relationships of the strata in the Wind River Mountains. The section was described by C. C. Branson in 1937 (p. 651), but the terminology is taken from a 1939 publication (pp. 1209–1210) showing the same beds. The locality is Bull Lake Creek. In his 1937 paper, Branson proposed to split the sequence that had previously been generally called Amsden into three units. The lowest of his three units consisted of 43 feet of cherty limestone underlain by 2–11 feet of "red and buff sandstone and shaly sandstone, breccia in places, shale cave filling in places." The 43-foot limestone is the zone of the invertebrate fauna described by E. B. Branson and D. K. Greger in 1918 (pp. 309–326) as of Ste. Genevieve age. For this lower unit of limestone and underlying red rocks Carl Branson proposed formation rank and gave them the name "Sacajawea formation." One of the reasons for giving these beds formation rank appears to have been that they were Mississippian, whereas the upper beds of the Amsden were Pennsylvanian. C. C. Branson considered the Sacajawea formation to range possibly from Salem to Ste. Genevieve age. He thus considered it pre-Chester. Beds that Branson probably would refer to the Sacajawea have been examined at several localities by the writer, but they contain very few fossils or none at all. Aside from the faunas described by E. B. Branson and Greger and by C. C. Branson in his 1937 paper, ostracodes have been described by Morey (1935, pp. 474–482) and by Croneis and Funkhauser (1938, pp. 331–360). These last two consider the ostracodes examined by them to be Chester.

Above the Sacajawea formation is a series of limestones about 60 feet thick that C. C. Branson believes is Mississippian, probably Chester, but few fossils have been found in it or, if found, have not been reported in publications. Above the limestone beds is a sandstone 80 feet thick that has been identified by some geologists as the Darwin sandstone. The

Mississippian-Pennsylvanian boundary is drawn at the base of this sandstone by some investigators; but, as elsewhere, there is little direct paleontologic evidence for its precise location at the base of the Darwin. Pennsylvanian fossils have been collected from a limestone some 80 feet above the top of the sandstone. Other geologists have rejected Branson's proposed Sacajawea formation on the grounds that in actual field practice it is not a mappable unit over an appreciable area. They have mapped the entire sequence of variable nonresistant beds between the Madison and Tensleep formations as the Amsden formation and have not ventured to indicate the precise location of the Mississippian-Pennsylvanian boundary within the Amsden. Some of these geologists have recognized the Darwin as a member of the Amsden. C. C. Branson, in 1939, proposed dropping the name Amsden. He would include in the Tensleep formation all those beds called Amsden by other investigators that are above the limestone beds referred by him to Chester? age. Geologists generally have not followed this suggestion, but it is used in figure 1 to illustrate various types of usage. The lower beds of the Amsden, as identified by most geologists, would be referred by Branson, as before stated, either to his Sacajawea formation or to the unnamed unit that he believes may be of Chester age.

SECTION IN SOUTHWESTERN WYOMING

Section 6, figure 2, measured by W. W. Rubey and the writer along the Covey cutoff trail in the Salt River Mountains, near Afton, Wyoming, has been selected to show features present in that part of southeastern Idaho and southwestern Wyoming where the Mississippian-Pennsylvanian boundary has been drawn along the boundary between the Brazer and the Wells formations. The many difficulties accompanying the use of this boundary as a mapping boundary in the field led Rubey to erect a new mapping unit that includes the nonresistant and alternating thin beds that occur in both the lower part of the Wells and the upper part of the Brazer. A silty sandstone in the lower part of this unit may be the Darwin sandstone, or a lenticular sandstone other than the Darwin. Mississippian fossils, including *Diaphragmus elegans* (Norwood and Pratten) n. var., *Camarophoria* cf. *C. explanata* (McChesney), and *Linoproductus ovatus* (Hall), were collected from a zone in a massive limestone about 400 feet above the base of the nonresistant unit, and *Chaetetes milleporaceus* Milne-Edwards and Haime and other Pennsylvanian fossils, including a new species of *Orthotetina* that appears to be represented in the western United States only in Pennsylvanian or Permian rocks, from the beds immediately above the massive limestones. Specimens of a species of *Lithostrotionella* occur at the same zone as the *D. elegans* mentioned above. The lists of fossils identified in 1931 and 1932 from this section will be published in full in W. W. Rubey's report.

MORGAN LIMESTONE AREA

The Morgan formation is typically exposed in Weber Canyon near the town of Morgan, Utah, where, in 1935, the writer measured a section including the Morgan, Brazer, and Weber formations (1936). The section has not been published because it seemed preferable to await detailed mapping to determine the extent and nature of the probable faulting. Girty had measured a section there some years before. The fossils collected during both investigations are being studied, but the studies have not been completed. A casual inspection of the col-

lections definitely confirms the statement of Blackwelder that the Morgan is, in part, of Pennsylvanian age. It has not been definitely determined whether Mississippian beds occur in the lower part of the Morgan. If the lower boundary of the Morgan is drawn on the basis of fossils and its age stated as Pennsylvanian, then, of course, Mississippian beds would be excluded from it. If, however, it is drawn on a lithologic basis that includes all beds in the nonresistant unit, then Mississippian beds might be present.

Since the writer's section was measured, A. J. Eardley (1944) has mapped in this area, and J. Stewart Williams (1943, p. 607) has published a description of the Morgan at the type area, where he found it to be 1,060 feet thick.

The Morgan formation has been extended south and east from the type area. Calkins and Butler (1943, p. 28) referred beds in the Cottonwood–American Fork area, Utah, to the Morgan(?). Others who have recognized the Morgan outside the type area include J. Stewart Williams (1943); Thomas, McCann, and Raman (1945); Huddle and McCann (1947*a*); McCann, Raman, and Henbest (1946); K. G. Brill, Jr. (1944); and Kinney and Rominger (1947).

The beds identified as Morgan by the above geologists vary considerably in lithology, and one might well ask whether it is advisable to carry the name Morgan so far afield. Thompson (1945, p. 31) has applied a new name, Hells Canyon formation, to beds in the Uintas that may be of Morgan age. Possibly his Younghall formation is equivalent to some part of the Morgan.

SECTION NEAR TABIONA, UTAH

Section 7, figure 2, is taken from a paper by Huddle and McCann (1947*b*). At this locality the Morgan formation is divided on lithologic grounds into an upper and a lower unit. The contact of the formation with the overlying Weber is drawn at the place where the sandstones cease to be dominantly red. This coincides generally, but not precisely, with the beginning of the massive, coarser sandstones and the termination of soft silty and shaly sandstones. Red and purple sandstones and shales and red cherts occur in the dominantly nonresistant lower part of the Morgan. The Mississippian-Pennsylvanian boundary is placed at the top of a black shale from which the writer has identified fossils as Mississippian. Fossils from the lower part of the Morgan, above the black shale, that have so far been studied by the writer are either too incomplete or of types too generalized and long ranging to indicate a definite age determination, but they suggest Pennsylvanian age.

SECTION NEAR VERNAL, UTAH

Section 8, figure 2, near Vernal, Utah, is condensed and generalized from a section, mostly along Ashley Creek, measured by D. M. Kinney and J. F. Rominger (1947) in the Whiterocks River–Ashley Creek area on the south flank of the Uinta Mountains, Utah.

As in the Tabiona region farther west, the Mississippian-Pennsylvanian boundary is placed at the top of a black shale, but the black shale is not so well exposed as in the Tabiona region. The Morgan is divided into two parts, both of which are tentatively considered to be of Pennsylvanian age. The collections need to be carefully studied, however, as they contain many forms that are generalized. The lower part of the Morgan is mostly limestone and is more resistant than at other localities where shales and sandstones are intercalated at short intervals. The upper part consists of three subdivisions, the lowest of which is mainly soft red shale, sandstone, or sandy shale.

It probably corresponds approximately to the upper unit of the Morgan in the area near Tabiona. The middle subdivision of the upper part of the Morgan is mainly hard buff to red sandstones, and the upper subdivision is tan limy sandstones and gray cherty limestones. It appears to the writer that the upper and middle subdivisions probably correspond to at least part of the beds considered to be Weber in the Tabiona region. The upper contact of the Morgan is drawn at the top of the highest limestone bed.

Stratigraphic sections here and in near-by parts of the Uintas have been made at or near the same localities as those already discussed by several geologists. The information in these separate investigations needs to be better integrated than it is at present, and work is now in progress to that end.

SECTION IN STOCKTON-FAIRFIELD AREA, UTAH

Section 9 of figure 2, condensed from one given by Gilluly (1932, p. 31) from Soldier Canyon near Stockton, was selected to show features existing in an area where the Mississippian-Pennsylvanian boundary is within the Manning Canyon shale.

Both the upper and the lower contacts of the Manning Canyon shale are gradational. Gilluly places the upper contact, with the Oquirrh formation, at the point where the limestones start to become more abundant than shales. The lower contact is drawn where shales become more abundant than limestones. The Manning Canyon, in contrast to other formations farther north that include the Mississippian-Pennsylvanian boundary, is almost devoid of red beds. Mississippian (Chester) fossils occur about 500 feet above the base of the Manning Canyon, and Pennsylvanian fossils occur about 350 feet higher. These are listed in Gilluly's report.

The Manning Canyon shale has been recognized at various places in north-central Utah. A section showing the Manning Canyon shale in the Wasatch Mountains area near Provo is given by Baker (1947). Nolan (1935, p. 31) described the Manning Canyon of the Gold Hill area, central western Utah. Bissell and Hansen in 1935 (p. 163) discussed briefly the gradational character of the Mississippian-Pennsylvanian contact in Spring Creek Canyon, east of Springville, Utah.

PROBLEMS IN PALEONTOLOGY

NEED FOR MORE PALEONTOLOGICAL DATA

The need for more paleontologic data is definitely shown in the preceding discussions of the few selected stratigraphic sections. Not only is the need for additional and larger collections from certain zones indicated, but there is also shown a need for more studies and better integration of collections already made. The problem of additional collections from specific zones in critical areas is not everywhere easily solved. In many mountain ranges the Carboniferous rocks are exposed mainly in areas of high altitude that are difficult of access. Furthermore, many of the beds are either unfossiliferous or contain very few fossils. Some beds that have fossils do not yield them readily, and it is difficult to obtain specimens that are well enough preserved to permit definite identifications. When closely related genera and species differ from one another only in some small internal character or in some particular type of ornamentation, as many do, large collections are frequently required to provide specimens to show adequately these characters.

If one could everywhere determine the

age of a formation or parts of a formation by making collections from a few localities known to provide good material, the problem would be simplified. Collections definitely located geographically and stratigraphically from many widespread areas are, however, needed to determine the age ranges of formations. The determination of the stratigraphic positions of collections in the Rocky Mountain region is frequently a problem because of faulting and folding. Especially are so-called "bedding-plane faults" likely to be missed and duplications or omissions of strata unnoticed. Stratigraphic sections and the fossil collections from these sections, in the Rocky Mountain and Great Basin areas especially, are, as a rule, on much firmer ground if the stratigraphic work is done in connection with rather detailed mapping.

SPECIES DIFFERENTIATION

Studies in systematic paleontology that deal with the relationships of the species of several genera need to be made. These should be made by paleontologists who have available large numbers of specimens, stratigraphically and geographically well located. Only by the study of large collections can differences between two individuals be correctly evaluated, that is, whether they are individual, varietal, specific, subgeneric, or generic. Extensive experience in applying zoölogical concepts in classification to closely related forms may substitute in part for the lack of large collections. The mere presence of some differences from a type specimen of a species does not, as all paleontologists know, constitute reasons for specific, or even varietal, differentiation. The ranges of variation within several species of the Rocky Mountain area need to be determined.

In the Rocky Mountain Carboniferous, certain individuals of the Pennsylvanian *Spirifer occidentalis-rockymontanus* group so closely resemble individuals of the Mississippian *S. increbescens-keokuk* group, as identified in the West, that one is forced to the conclusion that, if these species have been correctly identified, they either overlap or are not distinct species. Studies of western representatives of this group based on large, definitely located collections need to be made. The nomenclature should reflect as nearly as possible the actual relationships, and if in any instance it is desirable to combine two or more groups considered species into one, then that combination should be made. This would serve the cause of stratigraphic paleontology more than maintaining fictional differences would. Progress in paleontology, it is true, is made by finer and finer subdivisions, if they are truly useful, but progress is also made by combining so-called "species." It is frequently true that, when only a few specimens are known, several apparent species can be distinguished, whereas in larger collections species lines disappear and fewer species are recognizable.

Similar investigations need to be made of Mississippian and Pennsylvanian species of the genera *Composita*, *Chonetes*, *Lithostrotionella*, *Reticulariina*, *Linoproductus*, and others.

USE OF FOSSILS IN CORRELATIONS

One of the most important problems in the use of fossils for correlation in the Carboniferous of the Rocky Mountain region has just been discussed. More needs to be known about the ranges in variation within certain common species and about effective criteria for distinguishing these species, if they are distinct. Another problem that has also been mentioned lies in the difficulty of obtain-

ing large collections of well-preserved materials at critical localities and at critical stratigraphic zones. Criticism has been made of lists of fossils that contain many question marks and provisional identifications, but species cannot be positively identified when the diagnostic characters are not preserved. Correlations can rarely be positively made if species or genera cannot be definitely identified.

Not all species in the Mississippian and Pennsylvanian rocks in the Rocky Mountain region are long ranging or generalized. Some are distinct and are of definite stratigraphic value, along with other evidence, in the correlation of beds and zones. They have been called "index fossils,"[2] but the writer hesitates to use this term because too many fossils are index fossils only as long as relatively little is known about them. Since the writer first began paleontological work in the West, the range of many so-called "index fossils" has been extended so that they can no longer be used in the restricted sense of the term. One of these is *Archimedes*. For many years it was considered an index of certain zones in the Mississippian in this country; but in 1927 Girty and Gilluly (1932) discovered it above *Chonetes mesolobus* (*Mesolobus mesolobus* of recent authors) in the Oquirrh Mountains, Utah; and it has since been discovered in many places in Pennsylvanian rocks in the West and in the Permian in Russia. Other fossils, to mention a few, that have lost their early meaning as index fossils, within the writer's experience, include *Lithostrotion* (or *Lithostrotionella*), *Caninia*, *Leptaena analoga* (Phillips), *Leiorhynchus carboniferum* Girty, *Reticulariina spinosa* (Norwood and Pratten), and *Millerella*.

Few paleontologists have ever considered correlations in the Rocky Mountain Carboniferous that were based solely on one or two index fossils to be more than temporary, nor have they postulated the presence or absence of beds or zones on a similar basis. In using index fossils, the possibility always exists that the ranges of these fossils may be extended, and it is preferable to use several types of fossil evidence, where possible, for every correlation. Whole faunas are decidedly more useful in making correlations than are conclusions based on several index fossils or on fossils of any one class.

The province of this paper does not permit an exhaustive discussion of the various uses of fossils in correlation or the theories behind these uses. Paleontologists working on late Paleozoic rocks in the Rocky Mountains are generally aware of the many complex problems in any correlation and are usually on the alert for influences of less obvious factors. For instance, in parts of the Rocky Mountain region certain types or classes of fossils are relatively common in specific types of lithology and nearly absent in others—to cite one example, the large horn corals of the crystalline limestones of the Brazer. The possibility is always kept in mind that these corals are absent at certain stratigraphic zones merely because of ecological conditions (to be discussed more fully later). Another example: certain types or classes of fossils, such as crinoids and cephalopods, are relatively rare, and it is possible that their assumed excellence as zone markers is enhanced by their rareness. Still another example: several Mid-Continent

[2] An "index fossil" is generally defined as one that is characteristic of a specified time unit, more or less irrespective of facies, whereas a "facies fossil" is defined as being characteristic of a certain facies and crossing one or more time boundaries. In the larger aspect, of course, all fossils are index fossils and all fossils are probably facies fossils, but most geologists define and use the terms in the more restricted sense.

species have been identified in the Rocky Mountains, and it is possible that some of these species migrated into the Rocky Mountains so slowly that they occur there at a later time than in the Mid-Continent region. The possibility is kept in mind that the absences of species from certain zones may mean only inadequate collecting; also that classes of fossils only recently recognized and as yet little known may yield results that appear to be more definite than if they were better known. The value of relative abundance of specific forms in making local correlations has for a long time been realized and utilized in the Western states.

Not only do paleontologists use comparisons of total faunas and combinations of index fossils for correlations, but the reported first appearances of new forms and the reported extinctions of old forms are sometimes given special consideration. Certain evolutionary stages in specific species and especially genera, if adequately tested, and certain trends in evolution, if firmly established, are also used. An example of this last is the tendency for coarsely plicated Spirifers of the *rockymontanus* type to develop prominently in the middle Mississippian and to die out at the top of the lower Pennsylvanian (Des Moines equivalent). It is realized that whole faunas may transgress time lines, but such transgressions are relatively unimportant in correlations within local areas.

ZONATION

For many years rocks of Chester age have been generally separated from rocks of older Mississippian age throughout the northern and central Rocky Mountain area, and certain Mid-Continent zones have been recognized within the pre-Chester Mississippian rocks in several local areas. As early as 1873, Meek (p. 433) published a notice of a fauna from beds that he assigned to the Spergen limestone, which was then considered part of the St. Louis limestone, and that are probably now included in the Madison limestone in Montana. The presence of a zone of St. Louis or Meramec age in the Mississippian rocks of the Rocky Mountains has been mentioned in print by Willis (pp. 316, 324) in 1902 (St. Louis fossils identified by Stuart Weller in the Yakinikak limestone of Willis in northwestern Montana); by Girty (1927, p. 71), both published and unpublished; by Sloss and Laird in 1945; and by several others. The writer and others have recognized it in the field at several places where its presence has not been mentioned in published accounts. Other zones in the Mississippian that correspond to pre-Chester Mississippian zones in the Mid-Continent area have been recognized in local areas.

In 1927, in a general summary of the Mississippian rocks of southeastern Idaho, Girty (p. 71) recognized affinities of different faunules from the Brazer with those from the Spergen, St. Louis, and Chester strata. He realized, however, that the Spergen fauna may be a facies fauna rather than one that can be definitely correlated with the typical Spergen. The writer in 1935 and also in later years measured and collected from many stratigraphic sections in an effort to fix these and possibly other zones in the Brazer, as well as to determine possible zones in the Wells and Phosphoria formations. J. Stewart Williams and J. S. Yolton in 1945 recognized five zones in the Brazer limestone as exposed at Dry Lake, Utah. The lowest zone was correlated by them with the Warsaw formation and the next highest zone with higher beds in the Meramec group, possibly with the St. Louis limestone. Their

third highest zone is considered by them to be transitional between the Meramec and Chester groups, and the two upper zones are Chester. Most of the Chester forms cited by them are generalized forms that have not only a considerable stratigraphic range in the Chester but occur or are represented by very closely related forms both in younger and in older rocks. One exception, however, is *Diaphragmus elegans* (Norwood and Pratten). The proposed correlation of Branson's Sacajawea formation (lower Amsden of most authors) with Mid-Continent beds and of the units of the Big Snowy group with specific units in the Chester of the Mid-Continent has been discussed before.

On the Pennsylvanian side of the Mississippian-Pennsylvanian boundary, a zone of post-Morrow–pre-Kansas City age has been recognized widely for a long time. The zone was first recognized and identified widely by megafaunas (Williams, in Moore, 1944); but fusulinids attesting to its existence were also identified by Girty prior to 1927. During recent years fusulinids from the Quadrant formation of Montana, the upper part of the Amsden and Tensleep of Wyoming, the Wells formation of Idaho and Utah, the Oquirrh of Utah, and other formations in neighboring states have supplemented and confirmed the evidence from the larger invertebrates. Although some efforts have been made to divide this zone into two—a lower Lampasas and an upper Des Moines—it has not proved feasible on the basis of the megafossils. Some fusulinid workers also have not found such a division practicable.

Correlation of Lower Pennsylvanian beds with the Pennsylvanian formations of the Appalachian region rather than directly with the formations of the Mid-Continent areas was attempted by G. H. Girty in several written opinions, and he has identified, more or less provisionally, beds of Pottsville and post-Pottsville age. The writer does not believe that these correlations, when based on invertebrate megafossils, were very reliable as to detail, and Girty appears not to have considered them very reliable. In 1934, C. B. Read described a Pottsville flora, probably of middle Pottsville age, from beds exposed near Leadville, Colorado, from which Girty had described a macrofauna that he believed represented a zone that was "very early in Pennsylvanian time and probably older than any beds of the Kansas and Nebraska section." Read regarded this flora as older than the Glen Eyrie flora.

During the last five or six years, beds thought to be immediately above the Mississippian-Pennsylvanian boundary have been referred to a zone that is considered the equivalent of the Morrow of the Mid-Continent. Most of these references have been based mainly on fusulinid evidence. In general, the larger invertebrate fossils, where they are present, do not give adequate evidence—if, in fact, any positive evidence at all—for distinguishing the so-called "Morrow zone" from the zones bearing both Des Moines–Lampasas macrofossils and microfossils. This does not necessarily mean, however, that larger collections may not provide material whereby such a zone can be recognized by larger fossils.

L. G. Henbest (1946) seems to have been the first actually to designate beds in the area under discussion as of Morrow age, but the presence of very early Pennsylvanian beds in near-by areas had been noted before by C. B. Read, G. H. Girty, the writer (1944, p. 700), and others, and M. L. Thompson (1936) had previously suggested the presence of beds of Morrow age in the Black Hills. Paleon-

tologists had also identified a zone principally in the subsurface that they called "Morrow" in other parts of the general Rocky Mountain area, namely, New Mexico and Colorado. M. L. Thompson (1945) identified a zone correlated by him with the Morrow over a wide area in the Uinta Mountains; Williams and Yolton (1945, p. 1152) referred rocks in central-northern Utah to the Morrow; Thomas, McCann, and Raman (1945) referred rocks in northwestern Colorado and northeastern Utah to the Morrow; and H. W. Scott (1945, p. 1195) referred rocks in the sequence which he had identified as Amsden in central Montana to the Morrow.

In assigning rocks to the Morrow, Henbest appears to have laid considerable stress on the occurrence in them of the fusulinid genus *Millerella*, which was once thought to be restricted to rocks of Morrow age; but the range of *Millerella* is now generally considered to extend from late Mississippian to late Pennsylvanian time. Thompson recognizes the long range of the genus *Millerella* in Pennsylvanian rocks and the difficulty of using species of *Millerella* to denote different stratigraphic zones. He identifies his zone of *Millerella*, which zone name he applies to rocks of Morrow age, by the predominance of specimens of *Millerella* and the absence of the more highly developed fusulinids with which *Millerella* is commonly associated in Pennsylvanian rocks of post-Morrow age. Williams and Yolton base their assignment of beds to a Morrow age mainly on microscopic bryozoans and ostracodes identified by Chalmer L. Cooper. They also list larger fossils, but nearly all the larger fossils are forms which, if identifiable, have been collected elsewhere in beds associated with fusulinids of younger age than Morrow. Scott bases his age determination on *Millerella*, with supplementary evidence from other microscopic forms.

Despite the recognition of beds at the places mentioned above and at other places in the northern and central Rocky Mountains, correlated with faunal zones in the Mid-Continent, zonation studies useful over wide areas in the rocks near the Mississippian-Pennsylvanian boundary have not been published. One reason for this deficiency is the paucity of fossils and the poor preservation in many beds. Large collections of good fossils from many zones and localities are needed if zonation is to be based on trustworthy grounds. Another reason is the great number of relatively generalized long-ranging species. Still another reason is that faunal zones do not coincide in many instances with lithologic divisions, as they more or less do in some places. This reduces the general use and recognition of faunal zones in areas where the natural mapping units are not also faunal units.

In the Rocky Mountain area there are great thicknesses of rather uniform lithology, especially in the Mississippian rocks. This contrasts with the situation in the Mississippi Valley, where comparatively frequent alternations in deposition have occurred and where, consequently, the typical formations are thinner lithologic units. The Mississippian faunas in the Mississippi Valley were thus subjected to more frequent changes of conditions than were those in the Rocky Mountain area. Both the Mississippian and the Pennsylvanian rocks of the Mid-Continent were deposited in a different basin (though there were connections) than the one in which the rocks of the same approximate ages in the Rocky Mountain region were deposited. Although some species have been identified as Mid-Continent species, the faunas

in general are quite different. Most correlations of zones in the Rocky Mountains with zones in the Mid-Continent, when made in detail, have appeared based upon inadequate evidence. The writer has believed for a long time that either the southeastern Idaho section or one of the sections in central Utah in an area that has been mapped in detail and from which a great many collections have been made should be selected as a Rocky Mountain standard and that correlations in this region should be made in terms of this standard rather than in terms of Mid-Continent standards. There seems no reason to suppose that in this different basin the ranges of fossils would be precisely the same as in the Mid-Continent basin or basins. Broad correlations can be made, but only broad ones are justified at the present. Several instances are on record of ranges of Mid-Continent species, and even of genera, that are different from ranges in the Mid-Continent.

STRATIGRAPHIC PROBLEMS

CRITERIA FOR FORMATIONS

A study of the selected stratigraphic sections discussed on pages 331–340 shows that a considerable variety of criteria has been used for the definition and delimitation of formations near the Mississippian-Pennsylvanian boundary in the northern and central Rocky Mountain region. These criteria have given quite different results concerning the content and thickness of a formation in the same or in near-by regions. Most geologists have used lithologic criteria, but many have combined lithologic criteria with structural relations, such as unconformities, karst surfaces, or brecciation, or with faunal data. In some instances the location of an unconformity or the boundary of a faunal zone seems to have been the determining factor in the separation of one formation from another, and the lithologic change at the boundary only secondary. Few geologists definitely state that the basis for their formation boundaries is faunal, but those who refuse to put Mississippian beds in the same formation with Pennsylvanian beds, simply because of this difference in age, are nevertheless using faunal data as their main criterion.

Even those who have used lithologic composition as the main factor in the definition of their formations have not agreed on the type of lithologic criteria to use. It is probably unlikely that absolute uniformity in usage will ever be attained over wide areas or in different sections of the country; and it probably is not desirable. Geologists as a rule will use whatever they find in the particular region that provides mappable units, and the choice will depend not only on individual preferences but also on the character of the topography and climate of the particular area, the lithology of the rocks, and other factors.

In work in the Rocky Mountain region, the writer has been impressed with the usefulness of lithologic formations based upon features of the total lithologic composition of the formation more than that of formations based on the presence of some specific color; or on the highest or lowest occurrence of some particular type of lithology, such as the highest limestone or the lowest phosphate bed; or on the tracing of some conspicuous bed, such as a sandstone; or on the tracing of unconformities, either by faunal data or by matching unconformities seen in separate outcrops. Nearly all these criteria have been, or are being, used in the Rocky Mountain area, and local conditions might make any one of them more desirable than the others. The first ap-

pearance of a changed type of lithology especially has cogent arguments in its support.

Far more important than the adoption of any one particular type of criterion is the desirability of uniform usage, at least in local areas, to which, after all, formation names only apply.

During recent years detailed stratigraphic work and subsurface work have greatly increased in the Rocky Mountain area. This work has added much needed detailed knowledge regarding the individual beds that make up the formations and has resulted, in some areas, in the breaking-up of larger formations and the giving of formational rank to units that constituted subdivisions or merely unrecognized parts of the larger formations. In the writer's opinion, new and thinner formations are desirable if, and wherever, they conform to the generally accepted criterion that a formation "shall . . . meet the practical and scientific needs of the users of geologic maps" (Ashley *et al.*, 1933, p. 431). As stated in the remarks accompanying the stratigraphic code just quoted, "practicability of mapping is usually an essential feature" of a formation. It is only "under exceptional conditions" that this criterion should be waived. The test of the validity of new formations proposed for use in rocks of Carboniferous age in the Rocky Mountain area, whether surface or subsurface formations, would, in the writer's opinion, lie in the decision as to whether or not they could reasonably be supposed to form practical mapping units, under the conditions existing in the region at the present time, if exposed over a considerable area. The validity of any surface formation can be tested by mapping. Ample terminology exists for the recognition and designation of lithologic units below the rank of formation, so that distinctions as close as are desired can be recognized by some sort of designation. As indicated in the remarks explaining features of the code, formations may include parts of two systems or even major unconformities where there is a sequence of similar beds and where in practical work it is not useful to make a division.

Much has been written about the necessity of distinguishing between rock and time (or so-called "time") units in stratigraphic nomenclature, and interest in this question has been revived lately because of many examples of widespread confusion and because a third category—time-rock units—has been proposed. It is not appropriate to discuss this question here, but a satisfactory understanding of these differences, if agreed upon, would aid in achieving more uniformity in usage in some parts of the Rocky Mountains.

UNCONFORMITIES

Unconformities exist between and within several formations that occur near the Mississippian-Pennsylvanian boundary in the northern and central Rocky Mountains. Many of these are discussed in connection with the different stratigraphic sections, to which the reader is referred, but additional data on many of the unconformities are in publications from which no sections were selected or in the writer's files and notes.

Williams and Yolton (1945, p. 1150) show a widespread unconformity at the base of the Meramec division. Unconformities in local areas at this stratigraphic zone have been mentioned by others. A widespread unconformity occurs at the top of the Madison limestone over a wide area. The writer believes that this is mainly a pre-Chester or pre–Ste. Genevieve unconformity. In some places in Montana and Wyoming, beds that have been considered as young as St.

Louis in age have been included in the Madison; but in other places the upper part of the Madison limestone is of Osage age. The disagreement regarding the age of the Madison is beyond the scope of the present paper. Some of the disagreement may be due to a difference in interpretation of the boundaries of formations and groups in the Mississippi Valley, with which correlations have been attempted. An unconformity and overlap between the Heath and the Amsden formations that may be within the Chester has been described from Montana, but the age of the unconformity depends on the age assigned to the Amsden there. An unconformity occurs beneath the Darwin sandstone unit at some places where it has been identified in Wyoming. Unconformities have been placed at the Mississippian-Pennsylvanian boundary as delimited by fossils mainly because it appears that in some places fossil zones of the Mississippi Valley Basin are not represented here. Lithologic criteria that suggest terrestrial beds and other types of lithologic criteria indicate unconformities at various places in the Amsden formation, some of which are probably very local in extent.

PROBLEMS IN ECOLOGY AND PALEOGEOGRAPHY

Problems in ecology and paleogeography that are as challenging as those in paleontology and stratigraphy occur in the Carboniferous rocks of the northern and central Rocky Mountains. Mention may be made of a few. The occurrence in these rocks of black shales, dwarf faunas, oölitic limestones, great thicknesses of crystalline limestones containing few fossils other than corals, alternating terrestrial and marine beds, considerable thicknesses of red beds, finely laminated limestones, gypsums, and cross-bedded quartzites suggests the wide range of ecological conditions that existed during late Mississippian and early Pennsylvanian time. These also indicate the variety of ecological problems.

Existing data on the paleogeography need to be consolidated and published and new data added. Geosynclinal and shelf areas have been indicated in parts of the area. The location of major land masses is known in a general way, but details of the paleogeography, including precise locations and extent of major features, are not known. Relationships to other areas, such as the Mid-Continent and Pacific Coast areas, need to be more definitely worked out and sea connections more precisely located. Much additional data are needed on sources of sediments. Additional isopach maps need to be constructed; but these, to be widely understood, either will have to await unification of some of the stratigraphic terminology or will have to be accompanied by considerable stratigraphy, explaining the author's usages of formations.

Of quite a number of recent articles containing maps or discussions of paleogeographic features, papers by Nolan (1943) and Eardley (1947) are especially comprehensive and significant and contain valuable references to other literature.

CONCLUSIONS

1. As elsewhere in the United States, many unsolved problems are presented by rocks at and near the Mississippian-Pennsylvanian boundary in the northern and central Rocky Mountains.

2. The problems cover various phases of stratigraphy, systematic paleontology, stratigraphic paleontology, ecology, and paleogeography.

3. Adequate collections of well-pre-

served fossils are needed from critical stratigraphic zones at critical localities. Collecting has been limited in some places by the absence of marine invertebrates due to unfavorable conditions either during the deposition of the beds or for the preservation as fossils. At some other places it is limited by the difficulty of separating fossils from the enclosing rock. At many places, however, the small collections made have shown that more time and more experience in collecting would have yielded the larger and more varied collections needed.

4. The considerable amount of paleontologic data already obtained should be better organized for effective use.

5. Critical paleontologic studies of several common species are essential. These should be based on enough specimens to show the range of variation within each species. Species that are too narrow because of the lack of knowledge of the range of individual variation encourage erroneous and unsubstantiated correlations. Species that are too broad contribute to the difficulty of establishing recognizable paleontologic zones. The fact that certain species definitely are long ranging and do not contribute effectively to detailed zonation studies should be recognized and the nomenclature adjusted accordingly.

6. Paleontologic correlations should be based on several lines of evidence. Index fossils are very useful in combination with one another and with other faunal data, but changes in the stratigraphic ranges of some so-called "index fossils" argue for caution in the use of all of them. Correlation data from one class of fossils need to be checked against those from other classes wherever possible. No one class is of itself totally sufficient.

7. Correlations of restricted paleontologic zones in the Rocky Mountains with zones in the Mid-Continent region based on evidence from larger invertebrate fossils have in several instances been made on data that are inadequate in both places.

8. Detailed correlations within the Rocky Mountain area should be made mainly with typical sections within that area. There is little reason to believe that the Rocky Mountain and Mid-Continent areas, being distinct, though in places connected, basins, had the same geologic history. Nor did they necessarily have the same faunal zones, if one uses the term "zone" in a restricted sense, or precisely the same ranges of species. The gross differences in the faunas suggest that the ranges of species may, in fact, be quite different.

9. The use of fossils in determining the relative ages of beds in the Carboniferous of the Rocky Mountain area has been extensive and, despite the deficiencies of the data at some places, appear to have been as successful, though perhaps not so detailed, as in most other areas. Many hundreds of collections have been studied, and the age conclusions based upon these studies have been given to field men for further work. Many hundreds of square miles involving Mississippian and Pennsylvanian rocks have been mapped in detail, and some areas have been remapped on different scales. Many areas have been complexly folded and faulted, and other areas have been highly metamorphosed. Yet detailed remapping of some areas and mapping of neighboring areas have changed few of the paleontological age determinations.

10. Formations have been defined and their limits set by many different criteria. More uniformity than now exists, as to both criteria and terminology, is desirable. A big step toward uniformity would result from general agreement to

define and actually employ formations, whether surface or subsurface, as lithologic units which could be effectively mapped, or could logically be supposed to be mappable, on the ordinary scales of topographic quadrangle mapping used in the area where they occur. Smaller units could be given varying degrees of subformational rank to allow as fine discrimination as desired. Such a definition would not prohibit formations from containing unconformities, parts of two geologic systems, or several paleontologic zones or from varying somewhat in age from place to place. Even with such a general agreement, problems regarding the details of the lithologic composition of various formations, lateral gradation, and other points would remain to be solved.

11. Additional work on the Carboniferous rocks and their faunas in the Rocky Mountain area should be very thorough and detailed, or frankly interpretive in localities for which the data are inadequate. All types of previous knowledge should be utilized. Reconnaissance work has been done in nearly all areas.

12. The combination of detailed stratigraphic and paleontologic work with detailed mapping offers the best possibility of obtaining adequate and reliable data needed from the northern and central Rocky Mountain region.

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AMERICAN MISSISSIPPIAN AMMONOID ZONES

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ABSTRACT

No comprehensive study of our Carboniferous ammonoids has been attempted since the very beginning of the present century. Only three ammonoid zones can now be recognized in the American Mississippian system. These seem to be more or less equivalent to our Kinderhook, Osage, and Meramec-Chester beds, and they are characterized by the genera *Protocanites*, *Beyrichoceras*, and *Goniatites*, respectively. Locally, ammonoids are abundant in the Kinderhook and the Meramec, but elsewhere they are rare. Our Devonian and Mississippian systems are not known to carry a single ammonoid genus in common, and only two stocks cross the border between them. One of these, the prolecanitids, became quite varied in the Mississippian, and they have a considerable amount of stratigraphic value there. The other stock that continues into the Mississippian is represented by the genus *Imitoceras*. Its descendants underwent a great development during the Carboniferous and gave rise to most of the many diverse forms known from there. Although Kinderhook ammonoids differ materially from those of the Devonian, they are close to those of the Osage. The latter, known from only a few specimens, are quite distinct from Meramec-Chester forms, which are more or less transitional with early Pennsylvanian types.

KINDERHOOK MICROPALEONTOLOGY[1]

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ABSTRACT

Both published and unpublished information on Kinderhook microfaunas, together with significant macrofaunas and floras, are reviewed in an effort to assess the value of these microfaunas, particularly the conodonts, for stratigraphic correlation. Of all classes of fossils represented, the conodonts are best known because of their widespread occurrence in beds of this age and the relatively large number of papers published on them. The ostracodes, which occur in several zones, are relatively abundant but little known. Other kinds of microfossils, such as Foraminifera, holothurian and echinoid fragments, spores, ?radiolarians, and nepionic forms of many of the common larger fossils are the subject of few reports or have been neglected entirely.

INTRODUCTION

Any faunal or floral analysis of the Kinderhook, whether micro or macro, must take into consideration the whole biota, together with its stratigraphic relationships. Because the Kinderhook is the lowest or oldest of the Mississippian series, its faunas must be separated from those of the Upper Devonian, and the plane of division between the strata of the two systems must be located. There are numerous approaches to this problem. Because various methods have been used by workers during the past century, many and varied conclusions have been reached. Shall we base the line of demarcation on diastrophism and evaluate the fossils occurring above and below, or shall we accept the type or best-known sections and their contained faunas? On either premise—no matter which—many serious and often seemingly insurmountable difficulties arise. Tectonic disturbances do not occur simultaneously over the entire globe. The fossils that we now study lived and were entombed in the sediments of the seas which covered certain areas; at the same time, other areas were above sea level and undergoing erosion. The resulting patchwork quilt of strata and faunas must be pieced together by using all the various threads of evidence available to us.

The type Devonian is the incomplete section of strata in Devonshire, England, to which the name was hurriedly applied by English geologists in anticipation of the naming of the type section in New York State, where the best-known and most complete section is located. However, the type Kinderhook is in the Mississippi Valley, where, unfortunately, much of the excellent Devonian section present in New York is missing. Furthermore, different workers at different times have not agreed on what should be included in the Kinderhook at the type section and in adjacent areas. Some would include the black-shale formation, there called the "Grassy Creek"; others would exclude it. The unconformity below the black shale of the Mississippi Valley, considered from a diastrophic standpoint, is one of the greatest known on this continent.

Until recently our knowledge of "black-shale" stratigraphy was very patchy, and for many years little was done to correlate the numerous reports on the subject or to reconcile their differences.

In Europe, where differences of opin-

[1] Manuscript received January 15, 1948.

ion regarding the lower limit of the Carboniferous strata are as prevalent as they are in America, the conclusions reached have depended upon the class of fossils considered (Schindewolf, 1927). Coral students would place this boundary below the top of the Famennian (base of the Oberdevonstufe V), but those using cephalopods and plants place the line of separation above the base of the Tournaisian, at the base of the Unterkarbon I. Trilobites indicate that the boundary should be drawn at the base of the Tournaisian, but the brachiopod evidence indicates the base of the Strunian (K) zone. Jongmans and Gothan (1937, p. 22) selected the base of the Tournaisian Z zone as the Devonian-Carboniferous

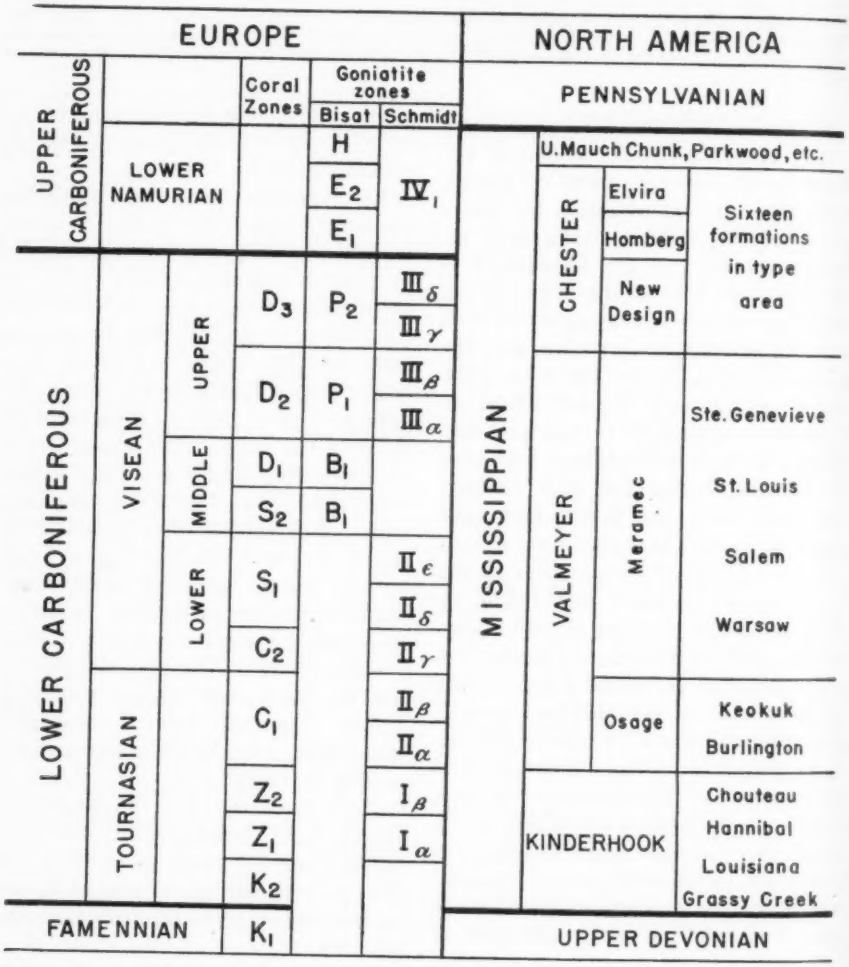

FIG. 1.—Chart showing the correlation of the American Mississippian with the Carboniferous of Europe

boundary, although the first Heerlen Congress (Jongmans, 1928) had agreed upon the base of the Strunian (K) zone (fig. 1).

In the second Heerlen Congress, a cephalopod fauna, the first appearance of which was regarded as marking the beginning of the Carboniferous, contained, among others, the genus *Protocanites*. The first appearance of this significant cephalopod genus in America is in the Louisiana limestone (Williams, 1943, p. 34).

J. Bandet (1945), in a detailed description of the stratigraphy and paleontology of the Dinantian of Tournai, shows that the calcareous shales and limestones of the *Assie de Maredosus* (Z_{1-2}) occur in the Lower Tournaisian. Williams (1943, p. 48) notes that individual genera in the Louisiana limestone suggest that the Louisiana is probably the time equivalent of the lower part of these beds. A photograph by Ubaghs (in Ancion, Van Leckwijck, and Ubaghs, 1943) shows (in fig. 5) thin-bedded black Namurian shales resting upon Famennien sandstones in the Liége syncline of Belgium. The systemic contact was placed below these shales.

TYPE KINDERHOOK

F. B. Meek and A. H. Worthen (1861, p. 288) defined the type Kinderhook to include "the beds lying between the Black slate and the Burlington limestone, which have heretofore been considered the equivalents of the Chemung group of New York," which later (1866, p. 288) they said included "the Chouteau limestone, the Lithographic [Louisiana] limestone and the Vermicular sandstone and shale [Bushberg-Hannibal] of the Missouri Report, that part of the Waverly sandstone of Ohio which overlies the Black slate of that region, and the Goniatite [Rockford] limestone of Rockford, Indiana."

Workers since Meek and Worthen have advanced many correlations of the strata in outlying areas with those of the type area. Stuart Weller (1905, p. 625) correlated the Louisiana limestone with beds 2–4 in his section (1900, p. 65) at Burlington, Iowa, and with beds 2 and 3 described by Worthen (1887, p. 27) in the type area at Kinderhook, Illinois (table 1). However, R. C. Moore (1928, p. 50) believes that the Louisiana beds do not correlate with the fine-grained limestones at Kinderhook and Burlington but that beds 2 at each place correlate with the Hannibal shale of the Missouri section. L. R. Laudon (1931, p. 365) agrees with Moore's correlation of bed 2, and J. S. Williams (1943, p. 40) believes that the Louisiana limestone is older than bed 2

TABLE 1

WORTHEN'S SECTION AT KINDERHOOK, ILLINOIS

	Feet
5. Loess capping the bluff	20
4. Burlington limestone	15
3. Thin-bedded, fine-grained limestone	6
2. Thin-bedded sandstone and sandy shales	36
1. Argillaceous and sandy shales, partly hidden	40

WELLER'S SECTION AT BURLINGTON, IOWA

	Feet
7. Soft, buff, gritty limestone	3– 5
6. White oölitic limestone	2– 4
5. Fine-grained yellow sandstone	6– 7
4. Fine-grained, compact, fragmental, gray limestone	12–18
3. Thin band of hard, impure limestone, filled with *Chonetes;* sometimes associated with thin oölite band	½– ¾
2. Soft, friable, argillaceous sandstone, sometimes harder and bluish in color, filled with fossils in the upper portion, the most abundant of which is *Chonopectus fischeri*	25
1. Soft, blue argillaceous shale (exposed)	60

at Burlington. Williams' important contribution gives strong stratigraphic and faunal evidence for the Carboniferous age of the Louisiana.

A recent paper of significance in relation to Devonian-Mississippian boundary problems is that by M. A. Stainbrook (1947, p. 302) on the brachiopods from the Percha shale of New Mexico and Arizona, who says:

> The Percha shale as now recognized should not be confused with formations such as the Sly Gap and Canutillo, which contain definite Devonian faunas. The Percha fauna is more closely related to that of the overlying Mississippian than to the underlying Devonian and the Mississippian system in New Mexico seems to begin with a body of black shale, the Silver member, similar to the basal black shale of the Mississippian system in many other parts of North America.
>
> The Percha fauna is most closely related to that in the lower part of the original Ouray limestone, which has generally been considered Devonian. The upper part of the Ouray is now correlated with the Leadville, has been consistently regarded as Mississippian. If the Percha be Mississippian, the lower Ouray is Mississippian also, and the Devonian is but scantily represented in Colorado.
>
> If the Percha is Mississippian, spiriferoids of the type of *Spirifer disjunctus* are demonstrated to have persisted beyond the close of the Devonian period. This is important in connection with the age determination of some other borderline Mississippian-Devonian formations.

A few of the ostracodes of the Percha shale and others from the "Devonian-Caballero" contact in New Mexico sent me by Frank V. Stephenson (1945) are similar to those found in the Underwood member of the upper New Albany formation. A more extensive collection from the Percha and associated formations should yield important evidence for comparison with the Mississippi Valley faunas.

Wilbert H. Hass (1947*a*, p. 1190) regards the Chappel formation as Upper Devonian(?) and Mississippian because the conodonts show five zones, as follows: (1) pre-Burlington, (2) pre-Welden, (3) Chouteau, (4) Bushberg and Hannibal, and (5) Grassy Creek. The Ives breccia, immediately below the Chappel, is assigned to the Mississippian. Neither the megafaunas nor the stratigraphy justifies this zonation, which seems to demonstrate the conformability of these strata in the Mississippian (see also Barnes, Cloud, and Warren, 1947).

NEW ALBANY SHALE

Huddle's paper on conodonts (1934) and Campbell's report on the stratigraphy of the black shales of central United States (1946) are important works and constitute a particularly complete study of the New Albany shale in its type area of southern Indiana (table 2). Although future work may alter some of Campbell's correlations with black shales in other areas some distance from the type area, his studies furnish the key to many problems that have confounded stratigraphers for many decades. Huddle's division of the New Albany into three zones, based upon conodonts, later amplified and applied to a much wider area by Campbell, proved to be the key to the stratigraphy.

Study of the relations of conodont faunas to one another and to other types of fossils, both plant and animal, now make possible the dating of at least two of the three members of the New Albany shale with reasonable certainty. The black-mud environment which began late in the Middle Devonian and persisted well into the Lower Mississippian was inhospitable to a normal marine fauna, so that, with a few exceptions, such faunas are found only at widely separated localities and horizons.

TABLE 2

CAMPBELL'S (1946) SECTION OF THE NEW ALBANY SHALE AT NEW ALBANY, INDIANA, AND VICINITY

	Feet
Rockford limestone	
Jacobs Chapel shale	
New Albany shale	
Henryville formation, fissile black shale, 24 species of conodonts, 16 of which are common to the lower Sanderson, D1	1.00
Underwood formation, soft, greenish, fossiliferous shale, with a layer of phosphatic nodules at the top	0.50
Sanderson formation, D	
3. Falling Run member, a layer of phosphatic concretions; *Colpocaris, Spathiocaris, Lingula melie, Orbiculoidea herzeri, Dinichthys, Rhadinichtys*, abundant conodonts, and 15 species of plants	0.33
2. Black shale, *Lingula* sp., fish dermal plates and teeth, conodonts, and 8 species of plants.	1.00
1. Black shale as in D2 with a layer of phosphatic nodules at the top; 46 species of conodonts, all common to the beds above	9.00
Blackiston formation, 60 species of conodonts, 40 species confined to the Blackiston	
Upper Blackiston member, C; hard, brittle, very thinly fissile black shale, with much pyrite, interbedded layers of gray shale, and calcareous concretions	
4. Black shale with layers of sandstone ½–1 inch thick and flat calcareous concretions; silicified *Callixylon newberryi*	6.50
3. Black shale, silicified *Callixylon*	10.00
2. Black shale with large calcareous concretions	8.00
1. Black shale with layers of gray shale and large calcareous concretions	7.00
Lower Blackiston member, B; black shale with coarse laminae, brown shale filled with *Sporangites*, and gray shale; *Barroisella campbelli* in brown shale and gray shale only	
6. Brown shale crowded with *Sporangites*, thin, sheety laminae and layers of gray shale; terminated by two layers of sandstone with *Sporangites* and *Barroisella*	5.00
5. Black-shale and gray-shale layers	20.00
4. Black shale with prominent widely spaced joints, which extend to the layer of pyrite below	15.00
3. *Spathiocaris* zone; gray-clay shale, which thickens to 15 feet and contains calcareous concretions at Hayden, 50 miles to the north	0.50
2. Brownish-black to coffee-brown shale, filled with *Sporangites*, thin, sheety laminae; *Barroisella campbelli* abundant and well preserved	1.50
1. Black shale, layer of pyrite at top, and four layers of ripple-marked sandstone 1–4 inches thick; the two middle layers contain thin lime concretions and much pyrite; *Barroisella campbelli, Dinichthys magnificus*, many worn fish fragments, worm borings and trails, and matted masses of unidentifiable plants	4.50
Blocher formation, A; black shale with coarse laminae; 44 species of conodonts, 39 species confined to the Blocher	
3. Black shale, interbedded with layers of ripple-marked sandstone	3.00
2. Black shale	3.50
1. Black shale with lenses and concretions of lime at the top, lenses of sandstone at bottom; *Leiorhynchus, Styliolina* abundant; *Schizobolus* confined to lower 1 foot	6.50
Layer of pyrite, 1–6 inches thick, often conglomeratic, is usually found at the base of the New Albany	
Hamilton limestones	

LOWER NEW ALBANY

The lower conodont fauna of Huddle contains 44 species and occurs in the lower 8–10 feet of the black shale, named the "Blocher formation" by Campbell. Of these species, 15 are common to the Devonian of New York, 8 are found in the Rhinestreet shale, 9 in the Genundewa limestone, and 3 in the Genesee shale. Associated fossils are *Chonetes lepidus* Hall, *Leiorhynchus quadricostatus* Hall, *L. limitare* Vanuxem, *Styliolina fissurella intermittens* Hall, *Tentaculites gracilistriatus* Hall, *Lingula spatulata* Vanuxem, and *Schizobolus concentricus* Vanuxem. G. A. Cooper (1942, pp. 1773–1774) correlated these beds with the Geneseo shale and Tully limestone of the New York section on the basis of the occurrence of *Leiorhynchus*, *Schizobolus*, and *Styliolina*.

MIDDLE NEW ALBANY

The next 75 feet of the New Albany shale in the type area is the Blackiston formation, which contains a different faunal assemblage. This is the zone of Huddle's middle New Albany conodonts, which contains 60 species, of which 3 occur in the Blocher formation, 15 in the upper New Albany shale, 10 in the Grassy Creek shale of Missouri, and 12 in the Chattanooga shale of Alabama. Nearly all the conodonts occur in the lower Blackiston formation (59 species); 19 are found in the upper part, and 18 are common to the two members. Branson and Mehl's (1933) so-called "diagnostic" Devonian genera—*Ancyrodella*, *Ancyrognathus*, *Icriodus*, *Polylophodonta*, and *Palmatolepis*—are found in this formation and, with the exception of the last, are not found in higher zones. Campbell (1946, p. 842) divided the Blackiston formation into two members on the occurrence of *Barroisella campbelli* in the lower part, where *Spathiocaris emersoni*, a new species of *Cypridinella*, and *Dinicthys magnificus* have also been identified. *Sporangites* (*Tasmanites*) are abundant in both the upper and the lower parts of the lower Blackiston formation.

Hass (1947*b*, pp. 138–139) disagrees with Campbell's correlation of the middle New Albany shale with the black-shale section in Ohio. He does not believe the Olmstead member of the Cleveland shale in northern Ohio is the correlative of the upper Blackiston formation. However, to place the Cleveland and Bedford shales at the position of an assumed hiatus in the New Albany (between the Blackiston and the Sanderson formations) disrupts a well-established correlation between the Bedford shale of Ohio, the Underwood shale of southern Indiana, and the Hamburg and Glen Park formations of the Mississippi Valley. Whether one considers this zone Devonian, Mississippian, or both in age does not invalidate this correlation.

Kindle (1900) many years ago collected *Barroisella subspatulata* and a number of goniatites from the *Spathiocaris* zone at Delphi, Indiana. Later A. K. Miller (1938) identified the goniatites as *Wernerоceras wabashensis* (Kindle), *Manticoceras delphiensis* (Kindle), *M. kindlei* Miller, and *M. unduloconstrictum* Miller. G. A. Cooper (1942, p. 1738) has also found the *Barroisella-Manticoceras* association in Michigan. This well-authenticated contemporaneity seems to establish the Devonian age of *Barroisella* and thus, in turn, fixes the age of the Blackiston formation, by reason of the conodonts which occur throughout the formation. The upper Blackiston beds have yielded numerous specimens of *Callixylon newberryi* at many localities. This species is also found in the lower Ohio shale of Ohio and the Woodford forma-

tion of Oklahoma. However, the presence of *Callixylon* specifically undetermined is, in itself, no assurance of Devonian age, as will be shown later.

UPPER NEW ALBANY

Branson and Mehl (1938*b*, p. 129) consider the break in conodont faunas between the Grassy Creek shale and Bushberg sandstone as the greatest known in this part of the section. The same break occurs also between the Blackiston and the Sanderson, the next formation above. However, Campbell (1946, p. 852) points out that a flora, *Dinichthys*, the Underwood fauna, and 20 species of Blackiston, Blocher, and Rhinestreet conodonts also occur above this break, all of which are regarded as Devonian by some geologists. The upper New Albany shale has been divided into the Sanderson, Underwood, and Henryville members from base to top. Other fossils that have been recognized in this zone are *Lingula melie*, *Orbiculoidea herzeri*, *Cladodus springeri*, and *Rhadinichthys*, together with a new conodont assemblage containing *Synprioniodina*, *Solenognathus*, *Siphonognathus*, *Falcodus*, and *Spathodus*—all of Mississippian affinity. These genera are represented by 17 species in the upper New Albany shale, 2 in the Blackiston formation, and 1 in the Blocher formation. The Underwood and Henryville conodonts, brachiopods, and plants constitute a significant faunal zone, with the Underwood fauna and the fossiliferous concretionary zone of the Falling Run member, in the middle.

In 1939, on the basis of 63 species of conodonts, I correlated a pre-Welden–post-Woodford shale in Oklahoma with the Bushberg and Hannibal formations of the Mississippi Valley. Eighteen of these species occur in the upper New Albany shale, 5 in the Blackiston, and 2 in the Blocher formation. On the evidence of *Lingula*, *Orbiculoidea herzeri*, the *Siphonognathus* group of conodonts, and the pre-Welden and Bushberg species, the Mississippian-Devonian contact is placed at the base of the Sanderson by Campbell (1946, p. 853). However, because of the occurrence of an even greater variety of conodonts in the shale in question than is found in the pre-Welden, I now believe it is the correlative of the Jacobs Chapel shale, which lies above the upper New Albany shale and below the Rockford limestone. This shift, though slight, would correlate the upper New Albany formations with the upper Woodford beds of Oklahoma. Both contain an identical phyllocarid crustacean fauna (C. L. Cooper, 1932) in phosphatic concretions, as well as many similar species of conodonts and other classes of fossils. The concretions from the Falling Run member in Indiana have furnished the following species: *Lingula* cf. *L. cuyahoga* Hall, *Orbiculoidea herzeri* Hall, *Colpocaris bradleyi* Meek, *C. elytroides* Meek, *Tropidocaris?* sp., *Spathiocaris woodfordi* Cooper, *S. tenuicostata* Cooper, *S. striatula?* Cooper, *Angustidontus seriatus* Cooper (C. L. Cooper, 1936), *Rhadinichthys*, *Dinichthys*, *Cladodus springeri*, and other fish remains, as well as the following plants: *Kalymma lirata* Read, *Periastron perforatum* Scott and Jeffrey, *P. reticulatum* Unger, *Archeopitys eastmani?* Scott and Jeffrey, *Callixylon browni* Read, *Clepsidropsis betrandi* Read and Campbell, *C. titan?* Read, *Cladoxylon* sp., *Siderella scotti* Read, *Lepidodendron boylensis* Read, *Reimania indianensis* Read and Campbell, *Protocalamites dorfi* Read and Campbell, *Asteroxylon setchelli* Read and Campbell, *Mensoneuron simplex* Read and Campbell, *Arnoldella minuta* Read, and *Sporangites* (*Tasmanites*) *huronensis* Dawson. This flora

has been considered Mississippian by several paleobotanists (Arnold, 1947, p. 1271; Hoskins and Cross, 1947, p. 1194).

Above the nodule-bearing Falling Run member is a thin, soft, greenish-gray shale, from which Huddle (1933) reported *Chonetes yandellanus seymourensis*, *Camarotechia exima*, *Rhipidomella vanuxemi newalbanyensis*, and *Platyrachella* cf. *P. macbirdei*, assigning a Devonian age to the shale. However, G. A. Cooper (1942, p. 1774) correlated this marine zone, named the "Underwood" by Campbell, with the Hamburg beds of the Mississippi Valley and the Bedford shale of Ohio, which, together with the Glen Park limestone, contain closely related faunas.

Sixty-nine species of conodonts occur in the upper New Albany shale, of which 24 are found in the Henryville beds and 16 in the Sanderson formation. *Lingula melie* and *Orbiculoidea herzeri* occur in the Falling Run member and the Henryville, whereas 3 species of plants are found in the upper New Albany shale. The conodonts, brachiopods, and plants form a biotic unit, in the midst of which the Underwood shale is found (Campbell, 1946, p. 853).

JACOBS CHAPEL SHALE

Above the New Albany formation lies a greenish-gray to dark-green glauconitic shale, less than a foot thick, which Campbell (1946, p. 885) named the "Jacobs Chapel shale." Faunally and stratigraphically it assumes an importance all out of proportion to its rather insignificant occurrence. In it is found again the prolific conodont fauna of a very similar zone found between the Woodford and Welden formations of south-central Oklahoma (C. L. Cooper, 1939), a locality some 700 miles away from the Jacobs Chapel locality in Indiana. As in the pre-Welden shale, most of the typical Bushberg conodonts occur in the Jacobs Chapel shale. Also found are *Meniscophyllum*, *?Chonetes*, *Rhipidomella*, *Platyceras*, minute gastropods and corals, trilobites, and ostracodes.

ROCKFORD LIMESTONE

The youngest formation of the Kinderhook section in southern Indiana is the Rockford limestone, which immediately overlies the Jacobs Chapel shale. For the most part, the Rockford limestone is a single massive bed that may reach a thickness of 6 feet in places but is commonly 2 feet or less in thickness. Very rarely this limestone is separated into two or more beds by thin shales similar to the Jacobs Chapel shale. It is significant that these shales carry the microfauna of the Jacobs Chapel beds, which is unlike the fauna in the shales immediately overlying the Rockford limestone.

STRATIGRAPHIC SUMMARY

In summary, the New Albany shale, together with other pre-Osage formations, comprises eight faunal and stratigraphic zones in Clark County, Indiana, and vicinity. These are, from the base: (1) the Blocher formation (Devonian), (2) the Blackiston formation, presumed to be Devonian because of the association of *Barroisella campbelli* with *Manticoceras* in the Delphi shale of northern Indiana and with *Tornoceras* in the Antrim shale of Michigan, (3) the Sanderson formation (Mississippian), which contains 43 of the 69 upper New Albany conodonts, with (4) the Falling Run member at the top containing phosphatic concretions with their characteristic crustaceans and plants, (5) the Underwood shale with its Hamburg-Bedford megafauna and an exotic undescribed microfauna, (6) the Henryville black

shale containing 24 species of the upper New Albany conodonts, (7) the Jacobs Chapel shale with its distinctive microfauna, and (8) the Rockford limestone, correlative with the Chouteau limestone of the Mississippi Valley section. Of these eight zones, 3–8 are with confidence assigned to the Kinderhook series. There is still some question about the age of zone 2 and its correlative, the Grassy Creek shale of Missouri. Zone 1 is thought to be definitely Devonian.

KINDERHOOK MICROFOSSILS

CONODONTS

All students of Paleozoic microfaunas are well acquainted with the conodont work of Branson and Mehl and their associates and students at the University of Missouri. Their first comprehensive work appeared in volume 8 of the *University of Missouri Studies* in 1933–34, wherein were described, among others, the conodont faunas of the Grassy Creek, Bushberg, and Hannibal formations. Later several papers appeared in the *Denison University Bulletin: Journal of the Scientific Laboratories* (1940*a;* 1940*b;* 1940*c;* 1940*d*), and the *Journal of Paleontology* (1938*a;* 1941), of which "New and little known Carboniferous conodont genera" (1941) is of special significance to this discussion. All of this work is summed up in Branson's *Geology of Missouri* (1944), which includes plates and fossil lists from unpublished theses written by graduate students at the University of Missouri, together with lists from a "phantom paper" by Branson and Mehl.[2]

The important work of Huddle (1934) on the New Albany shale has been mentioned, and the results of my own work on these fossils were given in several papers in the *Journal of Paleontology* (1931*a*, 1931*b*, 1935, 1939, 1945, 1947; Cooper and Sloss, 1943). Wilbert H. Hass currently working on conodonts from the Mississippian and Devonian formations of Texas, is the author of several recent contributions (1941, 1943; Knechtel and Hass, 1938; Hass and Lindberg, 1946). Except for papers on the Carboniferous published over half a century ago by G. J. Hinde (1879, 1900) and associates in Great Britain, these constitute the conodont literature of the Kinderhook.

There are, however, a number of undescribed faunas in my collections, including the prolific Jacobs Chapel fauna, the fauna from the shale breaks of the Rockford limestone of Indiana, that from the Kinderhook above the Mountain Glen shale and below the Springville formation of Union County, Illinois, and that from the phosphatic concretions of the Falling Run member in Indiana and Kentucky.

S. P. Ellison, Jr. (1946), has listed the stratigraphic ranges of most of the well-known conodont genera, and his chart shows all conodonts from the Grassy Creek and correlative formations below the Devonian-Mississippian line. However, listed in the Kinderhook are many of the common Bushberg, Hannibal, pre-Welden, and Jacobs Chapel genera, such as *Pinacognathus*, *Subbryantodus*, *Pseudopolygnathus*, *Siphonodella*, and *Solenodella*. The genera *Doliognathus*, *Scaliognathus*, and *Bactrognathus*, also shown in the Kinderhook, are indicative of a break in conodont faunas above the Rockford limestone that is equal or greater in importance than that claimed for the hiatus between the Grassy Creek fauna and those above it. The character-

[2] This paper, long delayed in publication (it was to have been published in 1943), will appear in the *Journal of Paleontology*. It lists several species, genera, and families from this report and from Shimer and Shrock's *Index Fossils of North America*.

istic Kinderhook species of the genera *Siphonodella*, *Solenodella*, *Macropolygnathus*, and nearly all the large number of species of *Polygnathus* are absent from the Rockford. Branson and Mehl (1941) described the new genera, *Doliognathus*, *Bactrognathus*, *Staurognathus*, and *Solenognathus*, from the Pierson of Missouri and the "Sycamore" of Oklahoma. Six species of the first two genera, together with many other new forms, are found in the shale overlying the Rockford and thus prove the Osage age of the Pierson and the limy shales above the Weldon of Oklahoma. Marvin Weller[3] believes the Welden limestone to be of Kinderhook age because similar species of trilobites occur in this formation and the Chouteau limestone of the Mississippi Valley.

The use of conodonts as index fossils has been criticized on the grounds that these fossils have not yet been properly evaluated and that their stratigraphic ranges are not sufficiently known to make them reliable markers. Many irregularities of occurrence or abnormal stratigraphic associations, such as "stratigraphic admixtures," "stratigraphic leaks," or "phantom formations," have been noted by some workers (Branson and Mehl, 1940*c*) in these fossils. However, as Guy Campbell (1946, p. 855) has pointed out, in the case of the New Albany shale, "failure to interpret the New Albany stratigraphy is due to incomplete and incorrect knowledge." It seems probable that in other instances seemingly abnormal conodont occurrences might be explained in the same manner or that a longer stratigraphic range should be recognized for some genera and species. It is indeed difficult to understand how "Welden conodonts were incorporated in the sub-Welden clay."

[3] Personal communication.

OSTRACODES

Scarcity of published papers, both in Europe and in America, makes this class of fossils less useful in the correlation of Kinderhook beds than they might be, in spite of a complete and presumably ostracode-bearing section on both continents. In 1939, E. Kummerow (p. 74), in comparing Lower Carboniferous ostracodes with those from adjacent formations stated:

> A comparison of the ostracode fauna of the Lower Carboniferous with that of the Upper Devonian becomes difficult owing to the imperfect knowledge of the latter. Only a part (Aparchitidae, Primitiidae, Zygobolbidae, Beyrichiidae, Kloedenellidae, Entomidae) have been worked in recent time (Matern, 1929).... Almost every type of the now well-known *Entomis*, except the genus *Richterina*, are found also in the Lower Carboniferous. Likewise near-related forms of *Entoprimitia* and graphiodactylids (*Primitia* and *Primitiella* of Matern) occur also in both formations. . . . Through the discovery of numerous species of *Entomis* in the shales of Dasberg near Neviges (Rheinland) and in the siliceous beds of the Huttales near Claustal (Hartz) was also the statement of Matern which disproved that *Entomis* species died away at the conclusion of the Dasberg stage and the *Richterina* species at the end of the Hangenberg stage. In comparison, a change in the ostracode fauna took place after the expiration of the Hangenberg stage.

Therefore, the important change in ostracode faunas in Europe occurred at the end of the Hangenberg stage, which is in the Tournaisian. In America the genus *Entomis* is known only from the Olentangy shale of Ohio (Stewart and Hendrix, 1945) and the Alfred shale member of the "Chemung" (Canadaway) of New York.

No Upper Devonian ostracode faunas —in fact, none younger than Hamilton (Warthin, 1934; Van Pelt, 1933; Coryell and Malkin, 1936; Stewart, 1936)—have been described from North America. Only two papers on Kinderhook ostra-

codes, both by P. S. Morey (1935,[4] 1936) have been published in this country; one describes a fauna from the basal Mississippian sandstone (Sylamore) and the other a fauna from the Chouteau limestone, both from outcrops in Missouri. A third paper, by R. S. Bassler (1932, p. 236) is on a fauna which was thought to be of Kinderhook age at the time that the paper was published but is now known to be of lower Osage age (Wilson and Spain, 1936). In my own collections are undescribed faunas from Texas, Oklahoma, Missouri, and Indiana.

These reports show the presence of several holdover Devonian-like forms, such as *Dizygopleura mehli* Morey, two species of the new genus *Plagiophrenodes*, and two species of small, flat, deeply punctuate *Amphissites*, without nodes or ridges, the latter somewhat similar to Hamilton forms. Carry-over genera from the Devonian also include new species of *Bairdia*, *Healdia*, *Graphiodactylis*, the latter represented by several species in the pre-Welden beds of Oklahoma, the Chappel formation of Texas, the pre-Springville (Darty) limestone of Illinois, and the Jacobs Chapel shale of Indiana.

The exotic fauna from the Hamburg-Bedford faunal zone in the Underwood shale of Indiana has, as far as known to me, no counterpart in Devonian or Carboniferous faunas of North America or Europe. It contains a terminal-spined form quite similar to *Ropolonellus*, although apparently it is not *R. papillatus* Van Pelt, from the Hamilton of Michigan and Ontario. The fauna also contains species of *Graphiodactylis* and *Kirkbyella*. Two forms similar to *Waylandella* and *Cornigella* give a strong Carboniferous aspect to this fauna.

[4] The horizon considered in this article (basal Mississippian) has been correlated with the Bushberg sandstone.

There are no Osage ostracodes known to me other than those from the Ridgetop shale of Tennessee, which contains the Devonian-like *Aechmina longicornis* (Ulrich and Bassler) and species of the ubiquitous *Tetrasacculus*, which first makes its appearance in the Hamilton beds of Ohio and Ontario, next in the Lower Louisiana limestone of Missouri, then in the Ridgetop formation, and finally high in the Mississippian in the Golconda and Glen Dean formations of the Chester series (C. L. Cooper, 1941) of the Mississippi Valley. The next higher ostracodes above the Osage are those described by H. L. Geis (1932) from the Salem (Meramec) limestone of Indiana.

FORAMINIFERA

Although Foraminifera are known to occur in many Mississippian formations, the only described forms are *Endothyra baileyi* from the Salem and St. Louis beds and a few genera from the Kinkaid (C. L. Cooper, 1947) (Chester) beds of Illinois which include species of *Millerella*, *Endothyra*, *Hyperammina*, *Palaeotextularia*, and *Trepeilopsis*.

Foraminifera have been observed in the Louisiana, Jacobs Chapel, Chouteau, and Rockford formations; a species of *Endothyra*, similar to *E. baileyi*, was collected from the pre-Welden shale. These faunas are all undescribed. In the Louisiana limestone are two species of *Ammodiscus*, while the Jacobs Chapel shale and Rockford beds contain many species of *Trepeilopsis*, *Glomospira*(?), and one species of *Thurammina*. Many identical forms also occur in the Chouteau limestone.

The Louisiana limestone is reported (Williams, 1943, p. 55) to contain forms that resemble *Hyperamminoides*, *Lituotuba*, and *Ammodiscus*.

MICROCRINOIDS

Allagecrinus americanus Rowley is common in the Louisiana limestone of Illinois and Missouri. Similar forms, but ones which may prove to belong to different genera and species, have been observed in the pre-Welden strata of Oklahoma, the Jacobs Chapel shale of Indiana, and the Chappel formation of Texas. Dissociated plates, probably of *Poteriocrinus* or *Platycrinus*, occur in the same zones.

OTHER MICROFOSSILS

Spores are abundant in the black shales of the New Albany type (Schopf, Wilson, and Bentall, 1944). *Sporangites* (= *Tasmanites*) *huronense* is the common and only described species, but further study will probably reveal others. This type of spore is known to occur in rocks as old as Ordovician.

Radiolaria have been reported (Henbest, 1936; Aberdeen, 1940) from the Caballos and Arkansas novaculites of Texas and Oklahoma. Designated as Devonian(?) by the United States Geological Survey, these formations are thought to be correlative with some part of the New Albany formation, probably the Blocher or the Blackiston, or both.

Holothurian plates, though undescribed in the Kinderhook, are represented by the numerous round, lacelike disks (*Ancistrum?*) found in many zones. Plates and other structural parts are known from higher Mississippian beds (Croneis and McCormack, 1932).

A few echinoid spines of an undetermined species have been noted in the Jacobs Chapel shale and correlative formations.

Annelida are represented in the Louisiana limestone (Williams, 1943, pp. 61–63) and Jacobs Chapel shale; *Conularia marionensis* Swallow, *Spirorbis kinderhookensis* Gurley, and *Cornulites carbonarius* Gurley are common in the Louisiana limestone. Scolecodonts are rare, but a few have been observed in the Underwood member of the upper New Albany shale.

Many nepionic forms show up in the microsamples, such as brachiopods, probably *Schuchertella louisianensis* Williams, gastropods, and ammonites, probably *Protocanites louisianensis* (Rowley).

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THE MISSISSIPPIAN FLORA[1]

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ABSTRACT

The Mississippian flora is one of the least investigated fossil floras of North America. David White recognized two phases—a lower, or Pocono, phase and an upper, or Chester, phase. The Pocono flora is characterized by *Triphyllopteris* and lycopods of the *Lepidodendropsis* type. The Chester flora is set off by the occurrence of *Cardiopteris polymorpha*, lycopods resembling the Old World *Lepidodendron volkmannianum*, and *Asterocalamites*. Both of these floras are distinct from the late Devonian below and the early Pennsylvanian above. The Reeds Spring formation of Missouri and the Wedington sandstone member of the Fayetteville shale contain the only Mississippian land floras yet described from the Mid-Continent region. The plants of the latter support the middle or early late Chester age indicated by the inverterbates. The flora of about forty species in the upper New Albany shale, described as Devonian, contains at least as many Mississippian elements. Most of the species found there, however, are restricted to this zone and consequently are of limited value in determining the age of the plant beds.

Although the existence of plants in the Mississippian has been known for more than a century, the flora of the rocks of this epoch has received relatively little attention. Not only is the flora very imperfectly known, but there is at present no one who is recognized as an authority on the Mississippian flora or who shows any immediate inclination to make it a subject of systematic investigation. Compared with the Pennsylvanian flora, the Mississippian flora is a small one. Localities where well-preserved Mississippian plants can be collected are few. Although some species occur in great abundance, the number of species that can be collected at any one place is small.

With the passing of the late Dr. David White, the largest and most comprehensive store of information on Mississippian plants ever possessed by one individual was irretrievably lost. During his lifetime Dr. White collected widely in the Mississippian, but his publications on the flora are few. His collections, however, are preserved in the United States National Museum, and it is earnestly hoped that some day they will be studied and described.

[1] Manuscript received January 3, 1948.

Dr. White set forth the general features of the Mississippian flora in the Appalachian trough in a paper published by the West Virginia Geological Survey in 1926. Except for changes in the names of some of the plants, the situation as White outlined it then remains essentially unaltered today. The few remarks I shall make are to a large extent restatements of what has been said before. White recognized a lower, or Pocono, phase in the Mississippian flora and an upper, or Chester, phase. These two are as distinct from each other as they are from the late Devonian below and the lowermost Pennsylvanian above.

The lower, or Pocono, flora, in addition to possessing obvious characteristics of its own, is clearly a derivative of the flora of the late Devonian. It is characterized throughout its entire lateral extent from eastern Pennsylvania to Tennessee by *Triphyllopteris*, a plant of fernlike aspects but of unknown affinities. The several species that have been named are difficult to distinguish. The Upper Devonian, on the other hand, is marked by *Archaeopteris*, which is used as a guide fossil in both North America and Europe. At almost any plant locality

in the Pocono and Price formations one may find fragments of the round-pinnuled plant resembling *Aneimites acadica*, described by Dawson from Horton Bluff, and which has been found across the Atlantic in the Cementstone group of the Calciferous sandstone of Great Britain. Some paleobotanists, including Robert Kidston, have regarded *Aneimites* and *Triphyllopteris* as congeneric and have advocated the use of the former name for both on grounds of priority. Whether they are distinct genera, I am not prepared to say, although it is evident even from casual examination that they intergrade. Other leaf types, bearing such names as *Rhodea*, *Cardiopteridium*, *Neurocardiopteris*, and *Sphenopteris*, are present in the Pocono flora. These will not be further commented upon.

The Lower Mississippian flora contains distinctive lycopods which are evidently derivatives of the Devonian *Protolepidodendron* and *Archaeosigillaria* and with which they are easily confused when not well preserved. The so-called "*Lepidodendron*" *corrugatum* described by Dawson from Horton Bluff is the same type of lycopod as "*L.*" *scobiniforme*, discovered by Meek in the Pocono. These lycopods are not true *Lepidodendra* because the cushions lack the characteristic oblique arrangement and the distinctive leaf-scar markings. They have recently been referred to the genus *Lepidodendropsis*, described by Lutz from the Culm of Bohemia. Imprints of true lepidodendrids and sigillarians have not been found in the early Mississippian; *Cordaites* has not been found in the Pocono or Price; and calamitean remains are fragmentary and scarce.

During a tour of the United States in 1933, Jongmans collected plants in the Pocono and Price formations. In collaboration with Gothan and Darrah, Jongmans (1937) described 11 new species and made a few generic transfers. Unfortunately for any American paleobotanist who may undertake a restudy of this flora, the holotypes of Jongmans' species are in the Dutch Geological Bureau at Heerlen. Jongmans, however, collected mostly at well-known accessible localities, so that it may be possible to designate topotypes of most of his species, although poor figures of some render their future identification virtually impossible.

In the Appalachian trough we know less of the Upper Mississippian flora than we do of the Lower, but the two stand out as distinct from each other. Most characteristic of the upper flora is a species of *Cardiopteris* which was assigned by White to *C. polymorpha*, well known in the late Lower Carboniferous of the Old World. Lycopods resembling the Old World *Lepidodendron volkmannianum* make an appearance, as does also *Asterocalamites*, which occurs in the late Lower Carboniferous elsewhere.

In the late Upper Mississippian a few forerunners of Pennsylvanian species come in, but only in the very latest of the deposits do species occur which render paleobotanical distinctions between the terrains difficult.

The most important contribution to the late Mississippian flora is White's account, published posthumously, of the flora of the Wedington sandstone member of the Fayetteville shale of Arkansas (1937*a*). The flora as described contains thirty-five species of ferns, seed-ferns, lycopods, calamites, and sphenophylls. Most of the forms are preserved as fragments, but they are sufficiently distinctive to support the Middle or early Upper Chester age indicated by the invertebrates. The flora is also similar in many

ways to standard Lower Carboniferous floras of Europe. Its Mississippian aspect is modified to some aspect by early Pennsylvanian and Namurian elements, but it contains no forms in common with the Middle Pottsville (Morrow) flora that occurs in the same region.

The Stanley shale and Jackfork sandstone of western Arkansas and southeastern Oklahoma were originally regarded by White as very late Mississippian. However, a careful analysis (completed in 1932) of a very fragmentary flora from these beds convinced Dr. White that, although they are older than the coal-bearing shale member of the Morrow, they are younger than any known Mississippian formations in eastern North America (1937*b*). Dr. White concluded that the Stanley and Jackfork are equivalent to the lower part of the Morrow group and hence are early Pennsylvanian.

Very few direct comparisons have been drawn between the Mississippian floras of the United States and floras of similar age in Europe, but it is generally assumed that they closely approximate the Lower Carboniferous floras of Great Britain and those of the Dinantian of the Continent. Jongmans (in Jongmans and Gothan, 1933) calls attention to the common occurrence of *Lepidodendropsis* in the Pocono and Price and the early Viséan of Bohemia. White (1913) has shown that the flora of the Pocono and Price is equivalent to that of Horton Bluff in Nova Scotia, which, in turn, ties up with the Calciferous sandstone flora of Scotland. Bell (1929) adopts White's assumptions and, in addition, correlates the Windsor flora with those of the Chester and the Middle and Upper Viséan.

Any survey of the Mississippian flora should include mention of the petrified woody stems described by the late Dr. J. E. Cribbs from the Reeds Spring formation of southwestern Missouri. Dr. Cribbs gave a detailed account of four types, one a species of *Cordaites* but the others representing genera previously unknown (Cribbs, 1935, 1938, 1939, 1940).

In connection with the foregoing account of the Mississipian flora, it seems appropriate to add a few remarks on the New Albany shale. Ever since 1850 the shale has been known to contain large petrified tree trunks. Recently, Charles B. Read and Guy Campbell (1939) have described a flora from the shale totaling forty-three species.

The large tree trunks in the New Albany shale belong, as far as we know, to one species, *Callixylon newberryi*. According to Campbell's recent work (1946), these trunks occur in a 16½-foot zone at the top of the Upper Blackiston member of the Blackiston formation. Since Campbell (1946) draws the Mississippian-Devonian boundary at the top of the Upper Blackiston member, *C. newberryi* is in the Devonian phase of the shale. However, fragments of *Callixylon* wood which appear to be specifically different from *C. newberryi* occur in the Sanderson formation which overlies the Blackiston. Therefore, if Campbell is correct in drawing the boundary where he does, *Callixylon* ranges beyond the Upper Devonian, where it principally occurs, into the Mississippian. This casual wandering of the genus beyond its alloted bounds, however, does not seriously impair its significance as a guide fossil, because it is still essentially a Devonian genus.

Most of the New Albany shale plants described by Read and Campbell come from the Falling Run member of the Sanderson, which, according to Camp-

bell's latest paper (1946), is Mississippian. This flora is a most remarkable one, not only for the variety of plant types present but for the fact that the plants are histologically preserved. In this respect it presents a marked contrast to others of comparable age in North America which are made up principally of compressions and impressions. This type of preservation (petrifaction) renders the flora one of exceptional interest to the investigator concerned with the anatomy of ancient plants. However, from the stratigraphical standpoint, such a flora presents special problems, and it is of more limited value than is a flora preserved in the more usual form. To be used for stratigraphic purposes, it should be compared with other floras preserved in a similar manner, and in North America no such floras of comparable age exist. As a consequence of the type of preservation of the plant remains, the New Albany shale stands quite alone as a landmark in the panorama of ancient plant life, just as the whole black-shale series is a sedimentary unit that is different in many ways from other sedimentary units of comparable age.

On the basis of six genera, Read (1936) and Read and Campbell in a joint paper (1939) assign the Sanderson (Upper New Albany) flora to the Devonian. These genera are *Asteroxylon*, *Polyxylon*, *Pietzschia*, *Protolepidodendron*, *Reimannia*, and *Callixylon*.

Before discussing the suitability of these six genera as age indicators in this particular instance, I wish to interject a general statement embodying a principle. When fossils are used in stratigraphic correlation, only those are suitable which have been previously observed to be restricted to, or principally restricted to, certain zones or happen to be confined within well-defined limits. At best, an element of relativity clings to the application of the concept of a guide fossil because detailed studies of newly discovered faunas or floras almost invariably result in an extension of the previously known range of some of the species. It may be said that a guide fossil remains a guide fossil only until it has been discovered at some place where it is not supposed to exist. With these thoughts in mind, we shall refer again to the six genera which Read and Campbell claim are sufficient to render the Upper New Albany flora "distinctly Upper Devonian."

If *Callixylon* were the only plant in the Sanderson formation and there were no contradictory evidence, we could assign the Sanderson to the Upper Devonian with complete assurance. However, Read and Campbell name about forty plants from this bed or its equivalent in southern Indiana and central Kentucky, from which they select five, in addition to *Callixylon*, which they claim are sufficient to place it in the Devonian. Among these, *Asteroxylon* is named, a genus previously reported twice, once from Scotland and again from western Germany. Both these occurrences are in the Middle Devonian, and they furnish all the data that we have concerning the stratigraphic range of the genus. The plant identified as *Asteroxylon* is illustrated by one figure of the transverse section of a stem containing a five-lobed wood strand which resembles that of *Asteroxylon* but which, in the absence of leaves and other essential characters, cannot be positively identified. There are many other ancient plants that have furrowed wood strands which might, on the basis of a cross section alone, be confused with *Asteroxylon*. *Pietzschia* has been reported once from the Upper Devonian of central Europe, but we probably know less of its range than we do of *Asteroxylon*. *Protolepido-*

dendron is a Middle and Lower Devonian plant known mainly from compressions of stems bearing numerous short bifurcated leaves. There are too many other lycopods similar to *Protolepidodendron* of whose structure we know nothing to use any of them as guide fossils. *Lepidodendropsis*, for example, is a Mississippian lycopod probably derived from *Protolepidodendron*, and we should take into consideration the likelihood of the two having similar structure. *Reimannia* has been known (until reported from the New Albany shale) only from the Hamilton of New York, and our entire knowledge of this genus was based upon one specimen. It was interpreted as the prototype of a well-known group of Carboniferous ferns, and consequently it is not surprising to find the same or a very similar plant in the New Albany shale. It is readily admitted that all the plants discussed above are suggestive of the genera to which they have been referred, but the published figures are the main basis for judgment. Either more material must be examined, or that which has been examined must be more completely described, before a final verdict can be given and we can be absolutely certain of their generic identity or of their value as age determiners.

Another fact that calls for caution in using the plants discussed above in dating the New Albany shale is that the whole flora is peculiar to this series. Of the forty-three plants listed by Read and Campbell, twenty-nine are newly named by these authors from the New Albany. Nine more had previously been named from it or from its counterparts in other states, and three are left without specific names. This leaves but two species—*Kalymma grandis* and *Periastron reticulatum*—that occur elsewhere, and neither of these is a recognized horizon marker. In other words, thirty-eight of the forty named species are endemic to the New Albany shale. One cannot deny that there may be Devonian elements in the flora, but it is extremely doubtful that they provide the necessary data to prove that the Upper New Albany shale is of Devonian age. To try to use them as proof of Devonian age is very likely to lead to erroneous conclusions. If these Devonian elements existed by themselves, one would be little inclined to deny their apparent value, but there are other factors involved upon which I shall comment briefly.

On the Mississippian side of the ledger, we find among the plants listed by Read and Campbell the following typical Lower Carboniferous genera: *Lepidodendron*, *Lepidostrobus*, *Cladoxylon*, *Stenomyelon*, *Clepsydropsis*, *Calamopitys*, *Kalymma*, *Steloxylon*, *Asterocalamites*, and *Lyginorachis*. Some of these genera do extend downward into the Upper Devonian, but they are essentially Lower Carboniferous; and on the basis of any of them, or any combination of them, one would assume Carboniferous age. No flora of proved Devonian age anywhere contains all these. Therefore, it seems that, when all the evidence is brought together and the correlative value of all the plant types is appraised, there is at least as much in favor of Mississippian as of Devonian age, and the balance is, the author believes, decidedly on the side of the Mississippian. In fact, when we look at a list of petrified plants from the Cementstone group of the Calciferous sandstone of Great Britain we find four genera (*Lyginorachis*, *Calamopitys*, *Stenomyelon*, and *Cladoxylon*) in common with the New Albany shale flora. When these particular genera are found together, one can come to almost no other conclusion than that they are of Lower

Carboniferous age. Then there are still other genera—*Clepsydropsis* and *Protocalamites*, for example—that are decidedly more at home in the Lower Carboniferous than in the Devonian. I therefore concur with Campbell, who, in his latest paper, draws the Devonian-Mississippian boundary between the Blackiston and the Sanderson formations. In his analysis of the New Albany shale series, Campbell comments upon the uniformity of conditions of deposition which extended from Tully to Kinderhook time; and it is therefore not surprising to find a goodly number of ancient plant types held over from the preceding Devonian flora and to find them intermingled with later ones that come in toward the close of the long interval of black-shale deposition.

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PALEONTOLOGICAL FEATURES OF MISSISSIPPIAN ROCKS IN NORTH AMERICA AND EUROPE[1]

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ABSTRACT

Comparison of marine fossil assemblages known from deposits of Mississippian age in North America and Europe shows many striking similarities in the nature and distribution of faunas but also brings out some strongly divergent characters. The occurrence of identical or nearly identical types of highly organized invertebrates, especially among the echinoderms and cephalopods, in correspondingly arranged successions of rather narrowly restricted zones affords a good basis for recognizing approximate stratigraphic equivalents in the two continents. Zonation of the European deposits is more detailed and better defined, however, than in most Mississippian sections of North America.

A conclusion of chief importance is that Mississippian deposits on both sides of the Atlantic are divisible in a similar manner into two main parts, classifiable as series. The Lower Mississippian rocks of North America, comprising Kinderhookian and Osagian beds, which have been called the "Waverlyan Series," correspond to the Tournaisian strata of Europe. Upper Mississippian formations, which are classed as belonging to the Meramecian and Chesterian portions of the American succession, collectively named the "Tennesseean Series," are judged on paleontological grounds to represent Viséan and lower Namurian deposits of the European continent. Distinctive upper Namurian marine fossils are unknown from North America, either in youngest Mississippian or in oldest Pennsylvanian beds; inasmuch as the Namurian seems everywhere to be an essentially conformable succession, no strongly marked break in sedimentation, such as marks the Mississippian-Pennsylvanian boundary in most parts of North America, is found at the summit of deposits of Mississippian age in Europe.

INTRODUCTION

The purpose of this paper is to offer in compact form a comparison of paleontological data pertaining to Mississippian deposits of North America and Europe. As part of the discussion directed to general appraisal of our progress in working out problems of Mississippian stratigraphy in North America, the focus of my contribution to this symposium is intended to be on paleontological zonation of the American Mississippian formations rather than primarily on intercontinental correlation. From this viewpoint, interest in European fossils belonging to the Mississippian part of the column hinges mainly on the manner and extent of their helping us to proper evaluation of our paleontological record. We are not concerned especially about identifying the European equivalents of the Keokuk limestone or other parts of our succession, and we are not interested primarily in fixing the stratigraphic position of various British crinoid-bearing beds in terms of our richly fossiliferous crinoidal strata. The objectives in the present comparative study are to learn how closely parallel the Mississippian faunas on opposite sides of the Atlantic run in their evolution and to judge how much the zonation of European strata, which is much better defined than that in North America, may throw light on work yet to be done by us.

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ZONATION OF EUROPEAN LOWER CARBONIFEROUS FORMATIONS

European deposits, which on the basis of contained fossils are recognized as equivalent to Mississippian formations of North America, are somewhat narrowly classified according to paleontological zones, and these are identified both in the continental portion of western Europe and in the British Isles. Based on sections in Belgium, the strata classed as belong-

ing to the Lower Carboniferous in Continental Europe are commonly called "Dinantian," and those defined as Upper Carboniferous (or by some geologists as Middle Carboniferous) begin with formations referred to the Namurian division, which also is named from outcrops in Belgium. Dinantian deposits are divided into Tournaisian beds below and Viséan strata above, which are widely recognized through Eurasia and northern Africa. Below the base of the Tournaisian, and included by some geologists in it, is a relatively thin stratigraphic division variously called "Etroeungtian" or "Strunian." The age of beds assigned to this division has been debated, and there is a tendency to regard it as a division distinct from Tournaisian. The presence of Upper Devonian elements, especially clymenid ammonoids, in Etroeungtian deposits supports their assignment to uppermost Devonian (Famennian), but there are also Carboniferous types of invertebrates. Consensus assigns the Etroeungtian to the base of the Carboniferous. It is noteworthy that the stratigraphic succession in Belgium and western Germany from Devonian into Carboniferous beds is conformable. Likewise, there is absence of a pronounced stratigraphic break at the top of the Dinantian, where a boundary is drawn between Viséan and Namurian beds.

In southwestern England, beds classed as Lower Carboniferous have been termed "Avonian" because of presumed slight difference in stratigraphic span of the section there, as compared with the type Dinantian; elsewhere in the British Isles they are commonly known simply as "Carboniferous limestones." The type Avonian section is along the Avon River near Bristol, and in this area a series of zones, delimited by means of corals and brachiopods, was defined some forty years ago. These zones, designated by index letters of the guide genera (K, Z, C, S, D) have come to be standard for reference of sections in other parts of the British Isles (fig. 1). Equivalents of Etroeungtian strata of Continental Europe are recognized as belonging to the K zone and are included in the lowermost Avonian. Near Bristol, the K beds rest conformably on upper Old Red sandstone of Devonian age. It is now recognized that the line of division corresponding to the boundary between Tournaisian and Viséan strata falls in the middle part of the C zone of the British succession, that is, between subzones called C_1 and C_2 (fig. 1). Overlying the Avonian or Carboniferous limestones comes the Millstone grit, which is classed as the lower main division of the Upper Carboniferous sequence. The dominantly clastic deposits of the Millstone grit are recognized as equivalent to the Namurian of Continental Europe.

The upper part of Dinantian beds in Germany, Belgium, and northern England is composed mainly of dark shale and siliceous limestone, constituting the so-called "Culm facies" (Kohlenkalk). The strata of this facies lack the corals and most of the brachiopod species that are used to zone the Avonian deposits, but they contain pelecypods, particularly *Posidonia*, and several sorts of ammonoid cephalopods. In northern England, Upper Dinantian zones, defined by means of mollusks, are overlain conformably by ammonoid zones of the Namurian sequence, and these are designated by index letters (B, P, E, H, R, G) of selected guide genera (figs. 1, 15, 16). The problem of correlating the coral-brachiopod zones and the ammonoid zones belonging to different facies was not easily or immediately solved; but the finding of interfingering relationships be-

FIG. 1.—Zonation of Lower Carboniferous rocks in western Europe, chiefly the British Isles, showing (*at left*) inferred correlation with American Mississippian divisions. The column at right indicates ammonoid zones, defined in Germany by H. Schmidt.

tween the two sets of deposits has now established correlation of the B zone with the S_2 and D_1 coral-brachiopod subzones, and the P zone with the D_2 and D_3 coral-brachiopod subzones. Corals and brachiopods corresponding to the E and H zones of the Millstone grit have been recognized, but these have not been defined as separately lettered zones (fig. 1).

Ammonoid zones in western Germany have been defined in a slightly different manner by Schmidt (1928) and by Hudson and Turner (1933*b*). In upward order, zones of *Protocanites*, *Pericyclus*, *Glyphioceras* [*Goniatites*], and *Reticuloceras* were designated by the Roman numerals I–IV, and these have been subdivided by Greek letters into subzones (fig. 1).

ZONATION OF AMERICAN MISSISSIPPIAN ROCKS

Mississippian deposits of North America have not been zoned comprehensively on the basis of invertebrate or other fossils. Also, there is far from complete agreement as to stratigraphic correlation of sections having different sedimentary facies occurring in various parts of the continent. Some broadly significant paleontological characteristics have long been recognized, however. Chief among these are the recognized dominance of a host of camerate crinoids in Lower Mississippian strata, in contrast to the virtual absence of these fossils in later Mississippian beds, and the abundance of pentremitid blastoids and the common occurrence of compound corals belonging to *Lithostrotion* in the upper part of the Mississippian succession. In the central Mississippi Valley, remains of the distinctive crinoid genera *Talarocrinus* and *Pterotocrinus* characterize higher Mississippian (Chesterian) strata, whereas these genera are entirely unknown in older rocks.

An effort to define faunal zones in the standard Mississippian section was published by Stuart Weller (1926) on the basis of extensive field studies made by him in Iowa, Illinois, Missouri, and Kentucky (fig. 2). He recognized fourteen zones, among which five were named in terms of brachiopods, one on a coral, and others by combinations of species representing bryozoans, crinoids, brachiopods, blastoids, gastropods, and pelecypods. The indicated stratigraphic distribution of the zones, according to Weller (1926, p. 324), was Kinderhookian, one zone; Osagian, two zones; Meramecian, four zones; and Chesterian, seven zones. Present opinion is that a majority of the zones defined by Weller are not widely applicable to classification and correlation of Mississippian deposits in North America.

Work on Kinderhookian rocks of Iowa has resulted in differentiation of eighteen paleontological zones (Laudon, 1931) (fig. 2). Some of these are known to be applicable in neighboring states, but the geographical distribution and usability of most of these zones is undetermined. Deposits of Kinderhookian age are seemingly many times thicker in the Rocky Mountain region of western United States and Canada than they are in the Mississippi Valley area. Some of the zone fossils discriminated in Iowa are known to occur in the western Kinderhookian (most of the Madison and equivalent beds).

Studies by Laudon (1947, p. 1161) of lower Osagian rocks in Missouri and Iowa have led him to define seven zones in the Burlington limestone on the basis of camerate crinoids and of blastoids (fig. 2). These zones were found to be clearly differentiated and recognizable along most of the outcrops and had been found applicable in northeastern, central,

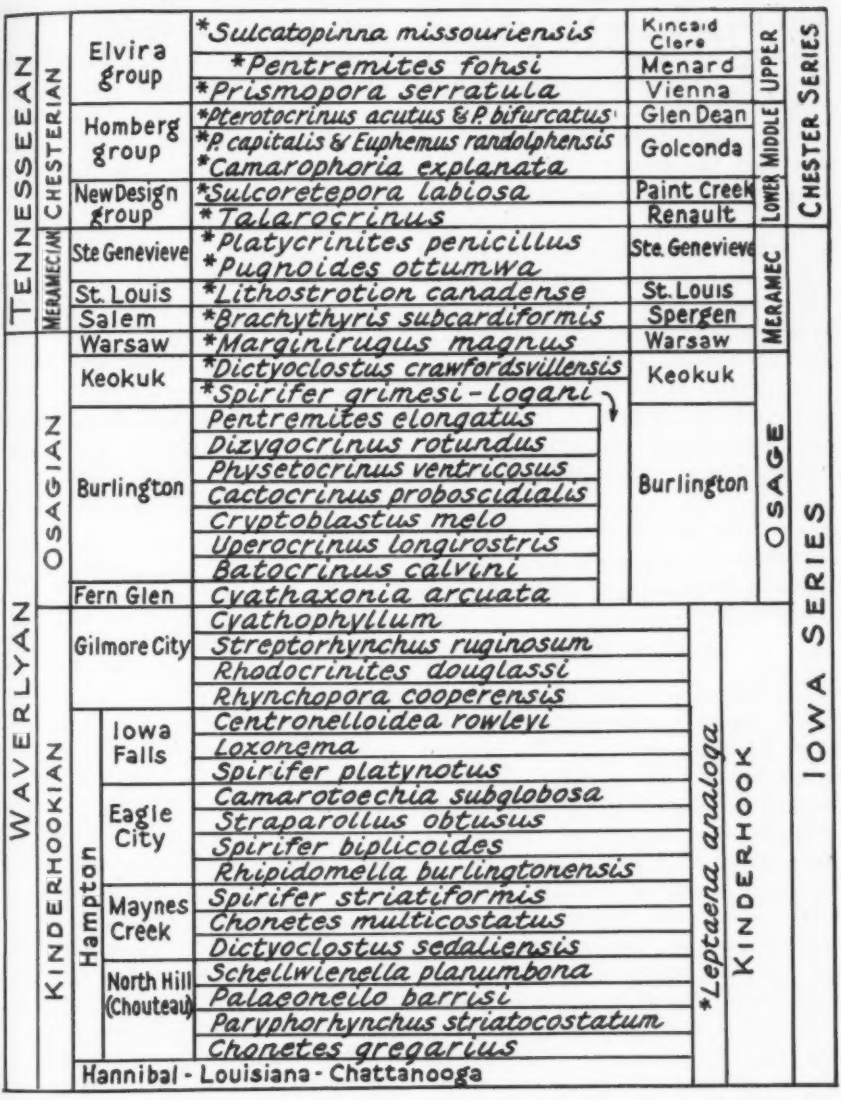

FIG. 2.—Paleontological zones in American Mississippian rocks. The stratigraphic classifications shown at right and the zones indicated by asterisks are according to Weller (1926). The stratigraphic classification at left is based on Van Tuyl, Laudon, and Moore. Paleontological zones below the Keokuk are after Laudon (1931, 1933) (except *Cyathaxonia arcuata*).

and southwestern Missouri. It is believed that other parts of the Mississippian section can be very satisfactorily zoned in terms of echinoderms; but published work along this line has not appeared.

Miller and Furnish (1940, p. 357) have suggested the placement of American Mississippian ammonoid-bearing beds in terms of European zones, but they have not defined or named such zones for the classification of the American section. They suggest that the middle Viséan *Beyrichoceras* zone, and perhaps most of the *Posidonomya* [*Posidonia*] zone of the upper Viséan of Europe, are equivalent to Meramecian deposits in North America, whereas the lower Namurian *Eumorphoceras* zone is recognized as Chesterian.

COMPARISON OF BIOLOGICALLY DEFINED GROUPS OF MISSISSIPPIAN INVERTEBRATE FOSSILS FROM NORTH AMERICA AND EUROPE

GENERAL STATEMENT

The following portion of this paper is devoted to the comparison of several biologically defined groups of Mississippian fossils, but it is recognized as decidedly incomplete, even though some of the tabulations presented are reasonably comprehensive. Available time has permitted organization of data sufficient only to support somewhat qualified conclusions. In the groups mainly studied, the nature of evidence now available is believed to be appraised with reasonable adequacy. A major difficulty has been the satisfactory determination of the stratigraphic placement of described fossils. Mostly, these data can be determined with assurance, but, because of inadequacy of records or lack of information as to stratigraphic correlations, especially among European records, some stratigraphic assignments are insecure. A factor that also affects part of the comparisons offered is correctness of generic identification. This means that among somewhat loosely defined genera, such as *Poteriocrinites*, *Pachylocrinus*, and *Actinocrinites*, for example, records of occurrence on opposite sides of the Atlantic probably fail to take account of actual distinctions of generic importance. The recorded distribution of many narrowly defined genera, like *Hypselocrinus* and *Ainacrinus*, which have been differentiated, respectively, in North America and Europe and are not now known to be represented by species on the other continent, is likely to be modified by future studies. In spite of these difficulties, many features of the comparisons are judged to be worthy of special notice.

FORAMINIFERS

Foraminiferal remains are fairly common in some Mississippian deposits, but they have not been studied extensively, and there is no present indication that they may be very useful for purposes of paleontological zonation. The genus *Endothyra*, which is common, especially in oölitic limestones such as the Salem and Ste. Genevieve, was originally described from Lower Carboniferous rocks of England, probably from beds of Viséan age. Studies by Edward Zeller, of the University of Kansas, have shown that shells referable to *Endothyra* are distributed from low in the Kinderhookian part of the American Mississippian section to Chesterian and that species having value for stratigraphic differentiation may be recognized. Liebus (1931) has described 58 species of Lower Carboniferous foraminifers from Germany; these are assigned to 26 genera. Included are species of *Endothyra* and forms classed as *Fusulinella*, the latter being almost cer-

tainly not *Fusulinella* but referable to *Millerella*. Examples of *Millerella* from Upper Mississippian rocks of North America have been distinguished by Zeller.

CORALS

Corals play a prominent part in the paleontological zonation of the Lower Carboniferous rocks in northwestern Europe, especially the coral-brachiopod facies of the British Isles. Hill (1938) has recognized three distinct facies faunas among the corals, which recur wherever a proper environment was established. These faunas are (1) a cyathaxonid fauna, composed largely of small solitary corals lacking dissepiments, occurring most commonly in shaly deposits; (2) caninid-clisiophyllid faunas, characterized by large solitary forms having dissepiments, occuring generally in light-colored well-bedded limestones; and (3) reef coral faunas, characterized by compound corals having dissepiments. The cyathaxonid faunas especially distinguish the rocks of Tournaisian age but extend into higher strata, whereas the other two assemblages are almost entirely developed in strata of Viséan and Namurian age.

Distribution of the most important coral species recognized in the British area is plotted in accompanying charts, in which forms reported by Hill are rearranged according to stratigraphic distribution, short-ranging types in one group (fig. 3) and long-ranging types in the other (fig. 4). Characteristic corals are illustrated in figure 5. The seeming distinctness of stratigraphic differentiation in terms of corals is well indicated. It is noteworthy that Hill has partly modified the zonal arrangement indicated by the generally recognized lettered subzones of the upper Viséan and has extended the zones to include lower Namurian deposits. Her Zone 1 is the same as D_1; it is the first reef-coral fauna, characterized by *Lithostrotion martini*, *L. minus*, *L. junceum*, *L. irregulare*, and *Lonsdaleia duplicata*. Coral Zone 2 comprises the D_2 subzone and about half the D_3 subzone (upward to the horizon of the Singlepost limestone). It is characterized by the presence of *Corwenia*, *Aulina furcata*, and the appearance of *Orionastraea* and *Palaeosmilia regia*. Coral Zone 3 comprises upper beds of D_3 and possibly the entire E_1 subzone; it is especially marked by the occurrence of *Lonsdaleia alstonensis*, *L. laticlavia*, and several other forms. The fourth coral zone belongs entirely in the lower Namurian, being made up mainly of the E_2 subzone; it is marked by *Aulina senex* and *A. rotiformis*, associated with forms of *Lithostrotion*.

Mississippian coral faunas from North America are very inadequately known, chief work during recent years having been done by Easton (1943*a*, *b*; 1944; 1945*a*, *b*, *c*); Kelly (1942), Merriam (1942), Jeffords (1943), and Sloss (1945). A compilation of the reported stratigraphic occurrence of some 70 coral genera reported from Mississippian rocks of North America and Europe is given in figure 6. Among these genera, more than 25 per cent occur on both sides of the Atlantic, and, in general, they have corresponding stratigraphic placement. Some forms, such as *Amplexus*, have relatively little meaning in the light of the present understanding of the polyphyletic nature of the types included in the group and the lack of basis for recognizing significant short-ranged forms. Other genera, particularly *Lithostrotion*, *Lonsdaleia*, *Diphyphyllum*, and *Dibunophyllum*, seemingly have much stratigraphic importance. These are almost exclusively forms characteristic of the

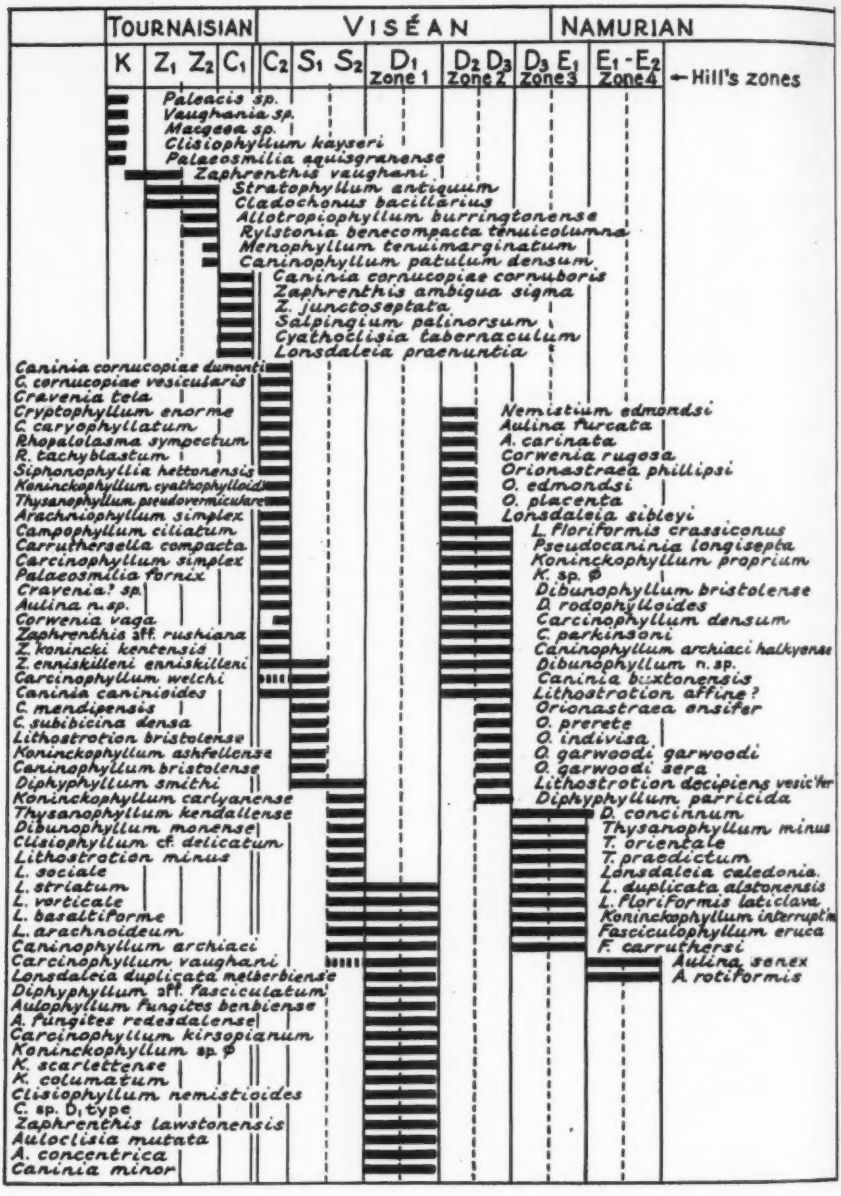

FIG. 3.—Short-range coral species of British Isles, arranged according to paleontological zones (data from Dorothy Hill, 1938).

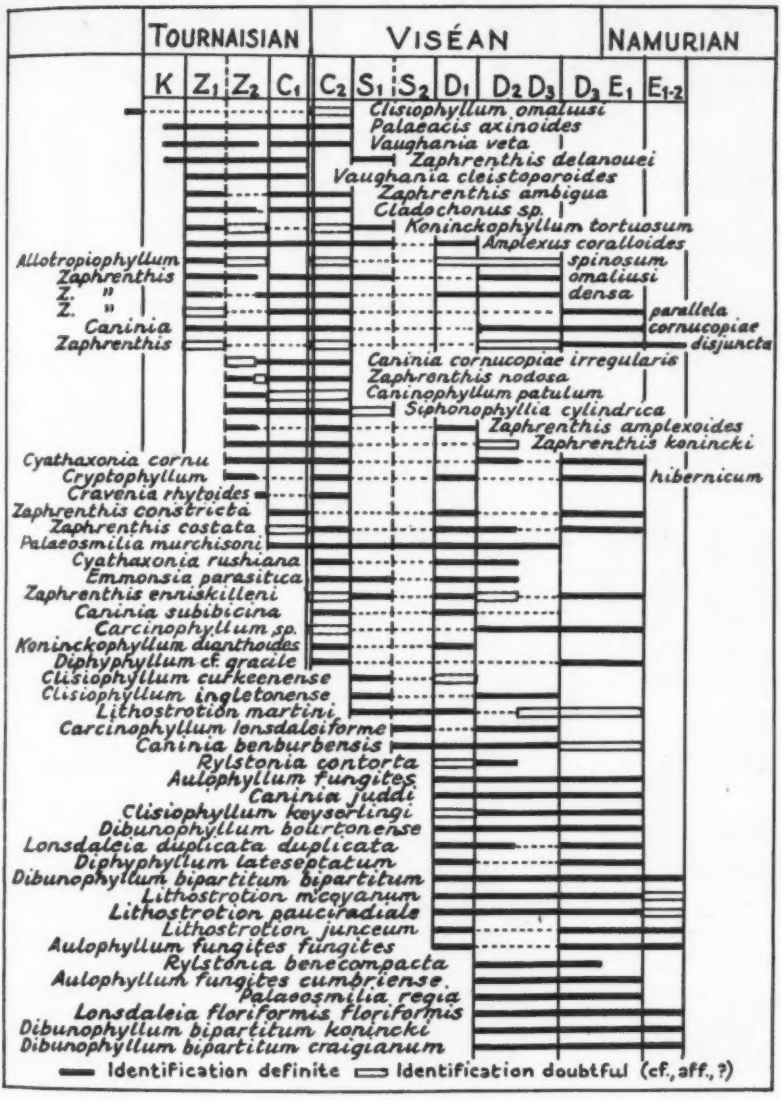

FIG. 4.—Long-ranging coral species of the British Isles, arranged by paleontological zones (data from Dorothy Hill, 1938.

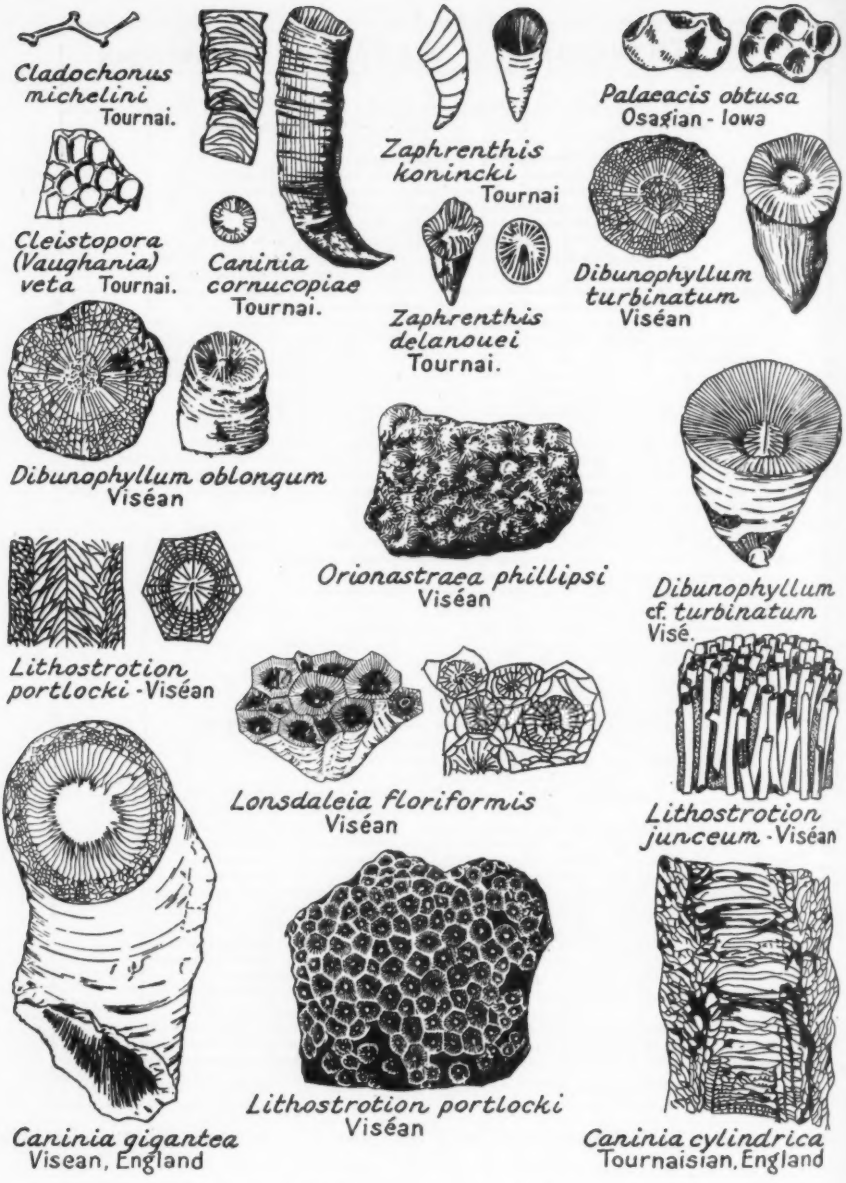

FIG. 5 —Representative Lower Carboniferous coral species, chiefly from the British Isles and Belgium (somewhat reduced).

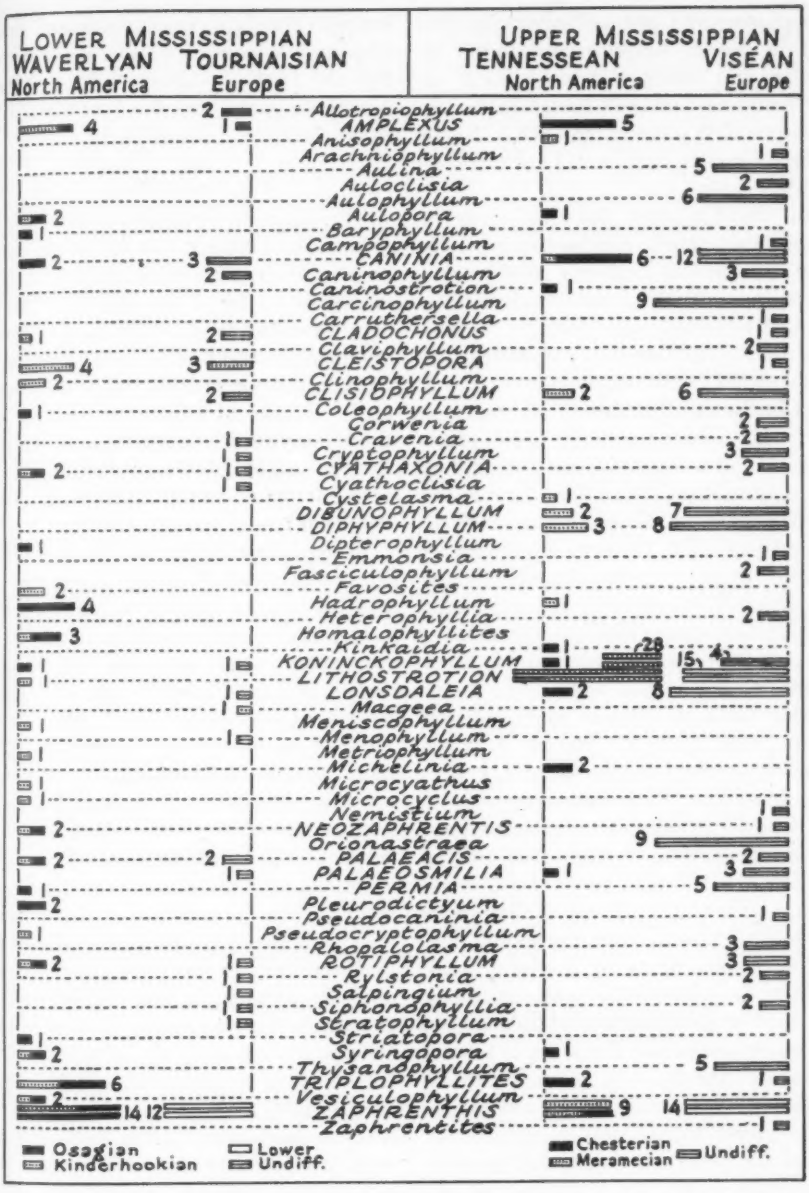

FIG. 6.—Comparison of the stratigraphic distribution of coral species recognized in rocks of Mississippian age in North America and Europe. Genera represented in both continents are indicated by capital letters.

Tennessean or Upper Mississippian Series in North America and found in Viséan and lower Namurian rocks of northwestern Europe. *Cleistopora*, on the other hand, is represented both in North America and in Europe in Lower Mississippian strata.

In the Canadian Rockies north of Jasper Park, thick Kinderhookian limestone containing *Leptaena analoga* and other characteristic brachiopods, associated with crinoids and blastoids, is characterized by extraordinary abundance of zaphrenthid corals, suggestive of the Z zone of the British Isles (L. R. Laudon, personal communication). The genus *Caninia*, for which the C zone, straddling the Tournaisian-Viséan boundary in the British area, is named, occurs both in Waverlyan and Tennesseean rocks of North America. A species of *Caninia* (*C. arcuata*) described by Jeffords (1943, p. 548) from lower Osagian rocks of New Mexico is reported to resemble very closely *C. cornucopiae* from upper Tournaisian beds of Belgium and England. Sloss (1945, p. 309) reports *Caninia cornucopiae* and *Lithostrotion* cf. *L. irregulare* from the Yakinikak limestone of northwestern Montana. *Caninia cornucopiae* ranges from Z_1 through C_2 of the British Mississippian zones, being most abundant in C_1; but closely similar corals are recorded from upper Viséan and lower Namurian strata of England (Hill, 1938, p. 6). *Lithostrotion* is almost wholly confined to Viséan rocks of Europe; *L. irregulare* is common in the upper Viséan. In North America this genus, including *Lithostrotionella* and *Siphonodendron*, is now represented by some 29 species (fig. 6), all but one occurring in Meramecian or younger rocks. The occurrence of two species of *Lithostrotion*, accompanied by *Dibunophyllum*, *Gigantella*, and *Striatifera*, in Mississippian rocks of the Pacific border (Merriam, 1942), indicates close correspondence with Viséan rocks of the British Isles, inasmuch as all these genera are characteristic of the high Mississippian rocks in western Europe.

BLASTOIDS

The echinoderms generally are judged to have much importance for faunal comparison of deposits of Mississippian age on opposite sides of the Atlantic. This is because of the relatively high structural organization and distinctive morphologic features among various groups and especially because of relative abundance of these organisms in many places. Therefore, a survey of the several kinds of echinoderms and their stratigraphic distribution merits special attention.

Among blastoids 19 genera, distributed among 8 families, are recognized in Mississippian rocks of North America and Europe. Eight genera are now known from America but have not been identified in western Europe; 5 are European genera, unrecognized on this side of the Atlantic; and there are 6 genera in common—*Codaster*, *Orophocrinus*, *Phaenoschisma*, *Mesoblastus*, *Orbitremites*, and *Pentremites* (fig. 7). Excepting *Orophocrinus* and *Pentremites*, species belonging to genera represented in both continents seem to be more common in Upper Mississippian deposits. In North America, *Codaster*, *Orophocrinus*, and *Orbitremites* are dominantly Lower Mississippian genera. *Pentremites* occurs in Lower Mississippian rocks on both sides of the Atlantic, but in North America it is mostly an Upper Mississippian form (67 species), whereas no representatives are known to occur in equivalent rocks of Europe. This is a striking contrast. *Schizoblastus*, *Carpenteroblastus*, and *Cryptoblastus*, which are important Lower Mississippian forms of North America, are unknown in Europe.

EDRIOASTEROIDS

Edrioasteroids are a relatively unimportant group of echinoderms, viewed from a stratigraphical standpoint, perhaps mainly because of their comparative rarity. One genus (*Lepidodiscus*) has been found in both North America and Europe, but in the former it occurs in Lower Mississippian rocks and in the latter in Viséan deposits (fig. 7).

CRINOIDS

The Mississippian Period was especially characterized by the abundance and extraordinary variety of crinoids, among which all three subclasses—Inadunata, Flexibilia, and Camerata—are well represented. A study of the distribution of genera and species of Mississippian crinoids is summarized in figures 8, 9, 10, and 12.

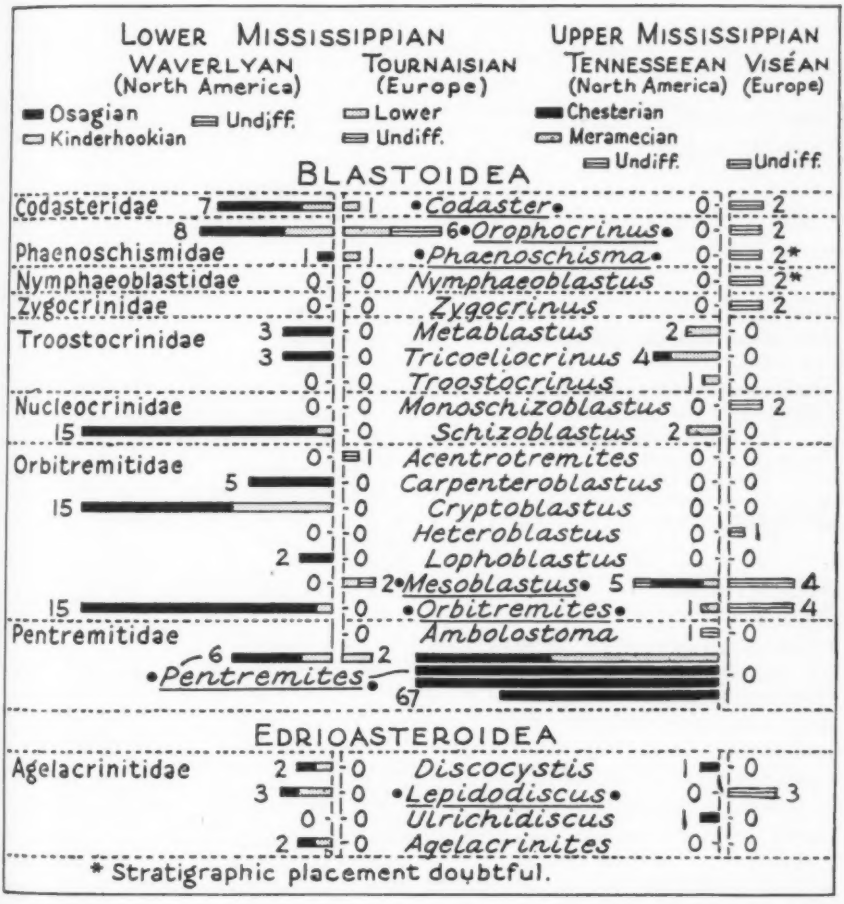

FIG. 7.—Comparison of Mississippian blastoids and edrioasteroids of North America and Europe. Genera common to both continents are underlined.

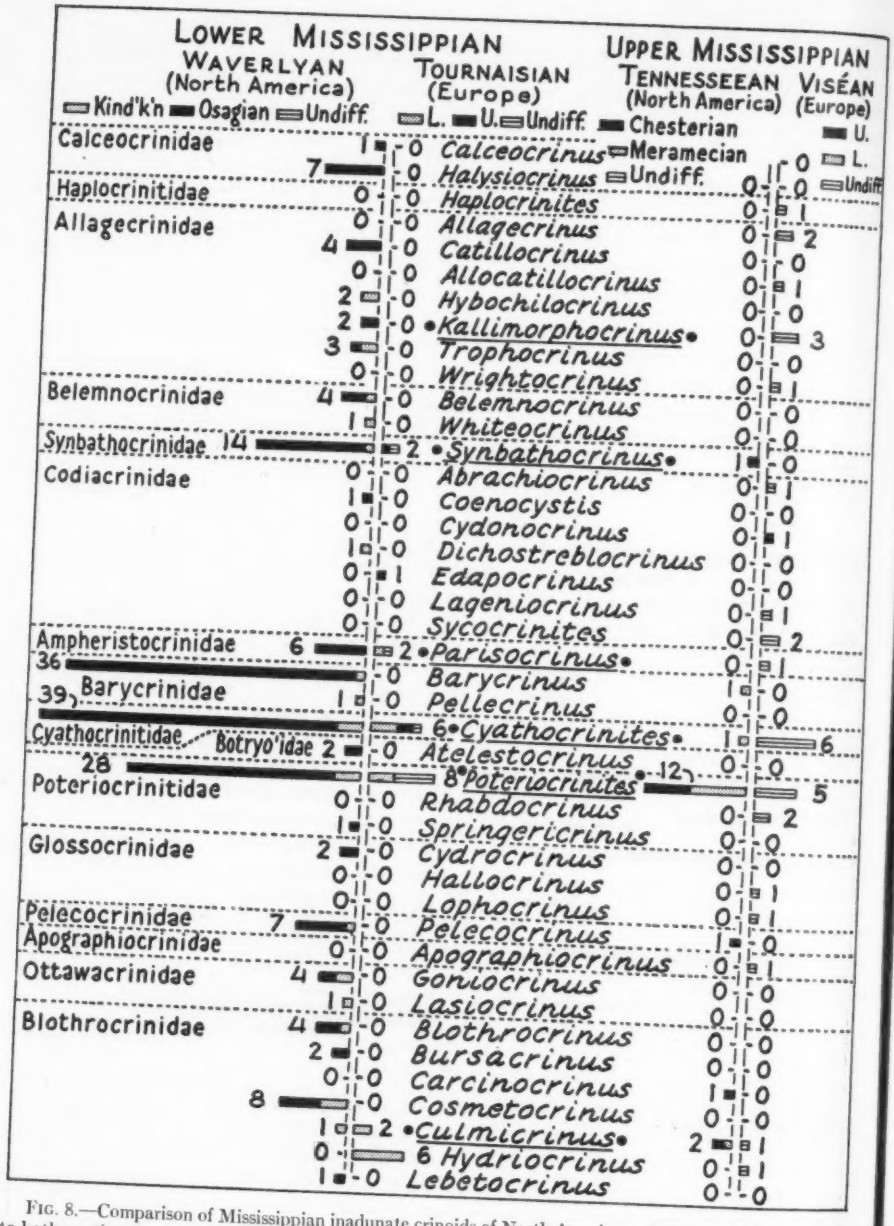

FIG. 8.—Comparison of Mississippian inadunate crinoids of North America and Europe. Genera common to both continents are underlined.

The very wide range of forms among inadunate crinoids is indicated by the numerous genera that have been recognized, and, as study continues, it is certain that many additional forms will be differentiated. The careful discrimination which is being employed in the definition of most genera signifies that the discovery of forms belonging to the same genus in North America and Europe furnishes reliable indication of a connection that may be interpreted to mean the existence of means for intermigration and probably close equivalence in geologic age. Conclusions as to age equivalence, however, are much less safely based on species belonging to genera of generalized form or simple structure, such as *Kallimorphocrinus* and *Synbathocrinus*, and probably such genera as *Cyathocrinites* and *Poteriocrinites*, as commonly identified, than in cases of many other inadunate genera having distinctive structural characters of cup and arms.

By and large, a survey of the inadunates does not indicate specially important points of similarity or discordance (figs. 8–10). It is of interest that the very distinctive, peculiarly specialized calceocrinids, especially *Halysiocrinus*, which are not uncommon in Lower Mississippian rocks of North America, have not been found in Europe. A distinctive but relatively unspecialized crinoid, *Barycrinus*, is found to be represented by 36 Waverlyan species in North America and in Europe. Distinctive inadunates that have importance in characterizing Lower Mississippian rocks of North America include *Catillocrinus*, *Belemnocrinus*, *Pelecocrinus*, *Blothrocrinus*, *Cosmetocrinus*, *Cercidocrinus*, *Coeliocrinus*, *Eratocrinus*, *Sarocrinus*, *Histocrinus*, and *Hypselocrinus*, none of which has yet been found in Europe. Similarly, diagnostic types of Upper Mississippian crinoids from North America that are unknown in Europe include *Dasciocrinus*, *Dinotocrinus*, *Rhopocrinus*, *Tholocrinus*, *Phacelocrinus*, *Eupachycrinus*, *Agassizocrinus*, and *Anartiocrinus*. Distinctive European inadunates occurring in Viséan strata, mainly in Scotland, include *Woodocrinus*, *Hydreionocrinus*, *Anemetocrinus*, *Aphelecrinus*, and *Scotiacrinus* (fig. 11); none of these genera has yet been identified west of the Atlantic.

Among common inadunate genera, probably the most significant are *Parisocrinus*, *Culmicrinus*, *Pachylocrinus*, *Scytalocrinus*, *Zeacrinites*, and *Phanocrinus*. The last-named two genera are especially characteristic of Upper Mississippian deposits. The genotype of *Graphiocrinus* is a Tournaisian species from Belgium and the British area; it is interesting to note that 14 species assigned to this genus occur in Kinderhookian and Osagian rocks of North America. No species of *Graphiocrinus* has yet been described from Upper Mississippian rocks, but the genus is represented by Pennsylvanian and possibly Permian forms from North America and Timor.

Among flexible crinoids, 17 genera of Mississippian forms have been described, and, of these, 6 are common to North America and Europe (fig. 10). These common genera include highly organized and distinctive forms, such as *Onychocrinus*, *Taxocrinus*, *Forbesiocrinus*, *Euryocrinus*, and *Wachsmuthicrinus*. Two genera of flexible crinoids—*Amphicrinus* and *Talanterocrinus*—described from western Europe but not known to occur in Mississippian rocks of North America, are definitely identified in Pennsylvanian rocks of this continent. The two lecanocrinid species referred to "*Stemmatocrinus*" (fig. 10) are from Osagian rocks of central Tennessee; they have been erroneously referred to an inadunate genus.

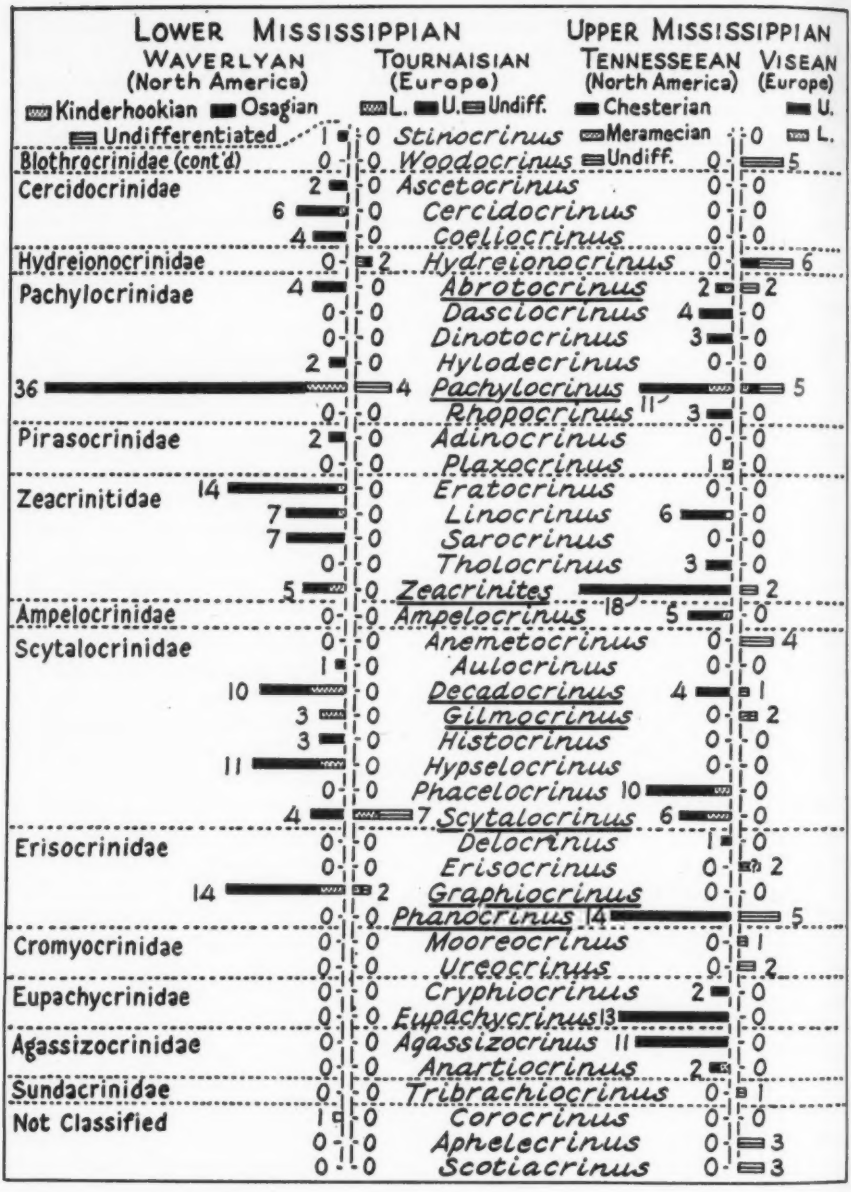

FIG. 9.—Comparison of Mississippian inadunate crinoids of North America and Europe (*continued*). Genera common to both continents are underlined.

In paleontological study of Mississippian rocks no group of fossils holds precedence over the camerate crinoids (figs. 11–12). This assertion does not rest on judgment that the camerates include the most highly organized crinoids, although forms are widely distributed geographically. Accordingly, the record of the camerates, as summarized in figure 12, is especially interesting in making a comparison of the Mississippian rocks of North America and Europe.

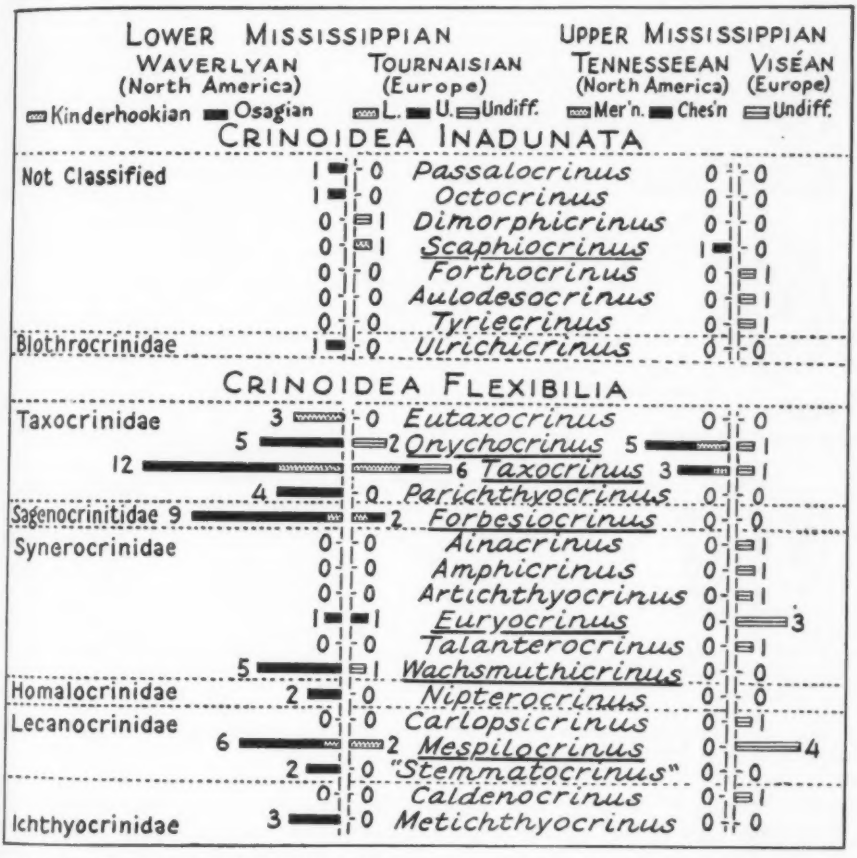

FIG. 10.—Comparison of Mississippian inadunate (*continued*) and flexible crinoids from North America and Europe. Genera common to both continents are underlined.

none have more complex structural elements; it contemplates mainly the amazing profusion and variety of these fossils, combined with observation of an extremely short stratigraphic range of almost all known species. Also, many

Among 35 now recorded Mississippian camerate genera, one-third are common to North America and Europe. The phylogeny of this division of the Crinoidea is not well understood, and it is almost certain that future research will

multiply the number of genera that are properly definable from these rocks which were formed at the time of the culmination of the camerate crinoid stock. Such new genera will be defined mainly by revisions of present known crinoids rather than by discovery of new forms.

periechocrinitids and their derivatives classed in the families Periechocrinitidae, Actinocrinitidae, and Amphoracrinidae; this stock began in the Silurian Period, and some representatives of it persisted into the Permian. American and European genera in this group include *Megi-*

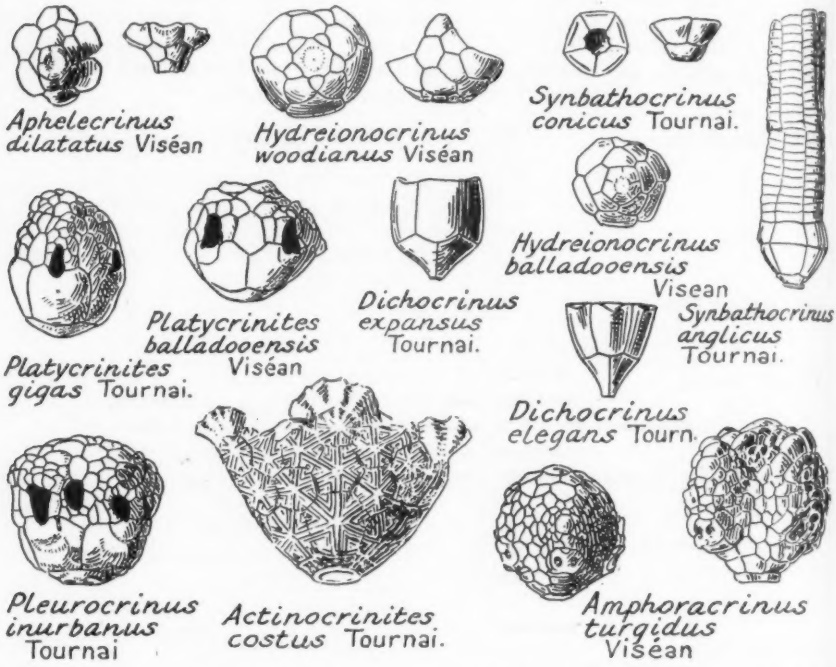

FIG. 11.—Representative inadunate and camerate crinoids from Lower Carboniferous rocks of the British Isles and Belgium (somewhat reduced).

The camerate crinoids now known from both sides of the Atlantic may be divided into four groups. The first comprises the rhodocrinitids, which began in the Ordovician and died out in Mississippian time; here belong *Rhodocrinites* and *Gilbertsocrinus*, which are wholly Lower Mississippian genera as known in North America but are present in both Tournaisian and Viséan strata of western Europe. The second group comprises the *stocrinus*, *Amphoracrinus*, *Actinocrinites*, *Cactocrinus*, and *Physetocrinus*, all of which are exclusively Lower Missisippian forms on this continent but are represented in part by Viséan species in Europe. A third group that includes *Dichocrinus* and *Camptocrinus* belongs to the family Dichocrinidae. This is a relatively long-ranging stock, which has its largest differentiation in Lower Mississippian deposits but occurs in both continents in

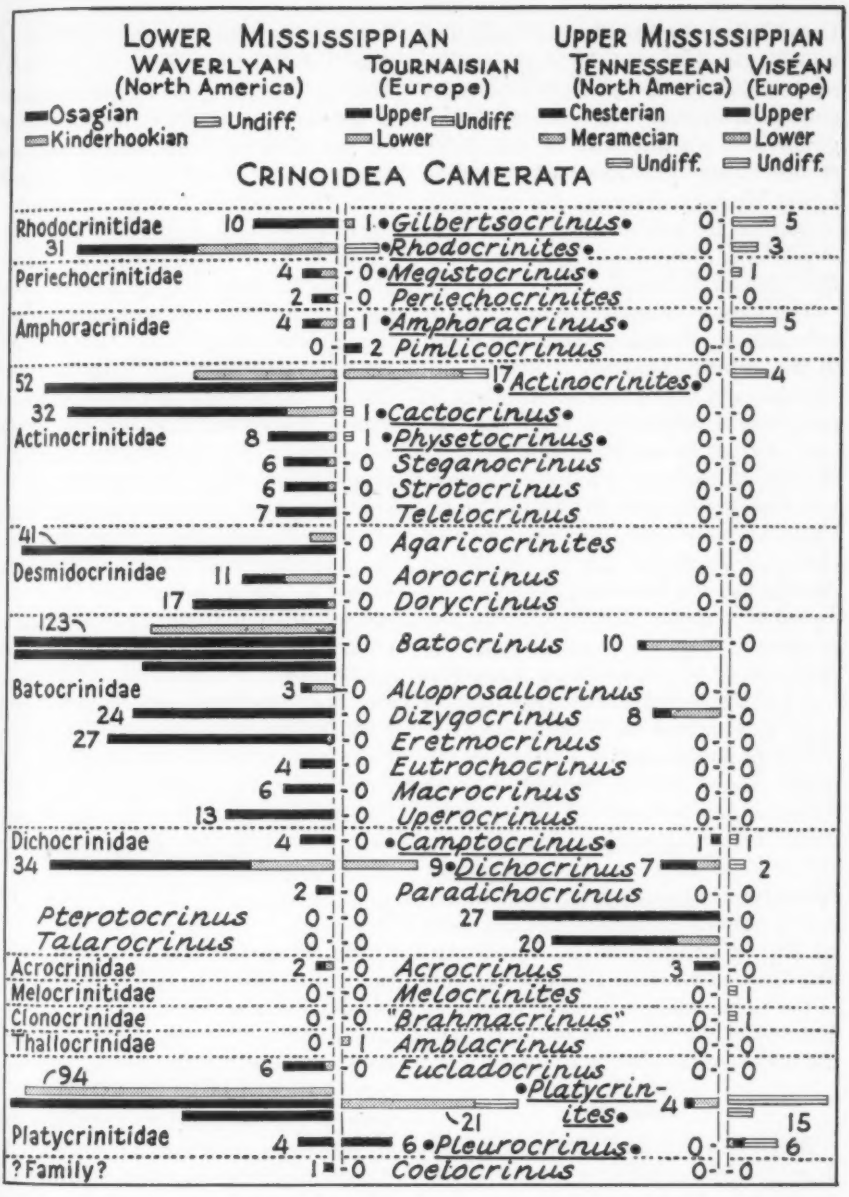

FIG. 12.—Comparison of Mississippian camerate crinoids from North America and Europe. Genera common to both continents are underlined. The disparity in distribution of the Desmidocrinidae, Batocrinidae, and part of the Dichocrinidae is especially noteworthy.

Upper Mississippian rocks as well. The fourth group is that of the platycrinitids, represented by the genera *Platycrinites* and *Pleurocrinus*. The record of this group is much like that of the dichocrinids. They are most abundant in Lower Mississippian rocks, but especially in Europe are well known in the Viséan formations. *Pleurocrinus* is recognized in the Permian of Timor.

The most remarkable contrasts in distribution of camerate crinoids are found in the families Desmidocrinidae, Batocrinidae, and Dichocrinidae. Although 69 species of desmidocrinids have been described from Lower Mississippian rocks of North America, not a single representative of this family is known in Europe. There are now some 218 described species of batocrinids, all of which are American, none European. They are assigned to 7 genera, but the greatly preponderant number (133) belongs to *Batocrinus*. Only 10 species of *Batocrinus* and 8 of *Dizygocrinus* are known to occur in rocks younger than Osagian. The record of the dichocrinids is partly quite different; among genera confined to North America, *Pterotocrinus* and *Talarocrinus*, which include 47 species, are exclusively Upper Mississippian, and *Paradichocrinus* is represented by two Osagian species. Evidently the prolific stocks included among desmidocrinids, batocrinids, and the *Talarocrinus-Pterotocrinus* part of the dichocrinids, originated in shallow seas of the North American interior and did not migrate into the European area.

ECHINOIDS

Much less abundant than the crinoids in most Mississippian rocks but very interesting and important wherever they occur are remains of echinoids. My survey of these fossils indicates that at present 22 genera of Mississippian echinoids have been defined, of which 9 are common to North America and Europe (fig. 13). Excepting *Archaeocidaris*, several species of which have been described on the basis of individual plates and spines rather than on relatively complete tests, the fossils of this group are all of such morphologic complexity and differentiation that their occurrence stratigraphically must be deemed to have much significance. *Lepidechinus* among the lepidocentrids and *Pholidocidaris* among lepidesthids are found on both sides of the Atlantic in Lower Mississippian strata but have not been discovered in younger rocks. On the other hand, the genus *Melonechinus*, of the family Melonitidae, is an exclusively Upper Mississippian echinoid that is represented by 11 American species and 2 European forms. So far as known, the American species are from Meramecian formations. Other common genera—*Perischodomus*, *Lovenechinus*, *Palaechinus*, *Archaeocidaris*, and *Maccoya*—are recorded from both Lower and Upper Mississippian rocks. In general, stratigraphical distribution of the echinoids gives important confirming evidence to that derived from the camerate crinoids and some other echinoderms.

BRYOZOANS

The bryozoans, called "polyzoans" in the British Isles, are generally similar in Mississippian rocks of North America and Europe, but this group of fossils does not now furnish much help in a comparative paleontological study. I have not undertaken to tabulate data on described genera and species. Much work remains to be done on American Mississippian Bryozoa, and probably the same is true in western Europe.

Fenestrellinids are reported in both Lower and Upper Mississippian rocks of

the British Isles and from Viséan strata on the Continent. Nekhoroshev (1932) has identified several species from Viséan rocks of western Germany with Osagian and Tennesseean species described from North America.

trasted with the absence of this genus in Lower Carboniferous rocks of western Europe. Also, *Sulcoretepora*, which is represented by several American species, seemingly is not recorded from Lower Carboniferous rocks of Europe, possibly

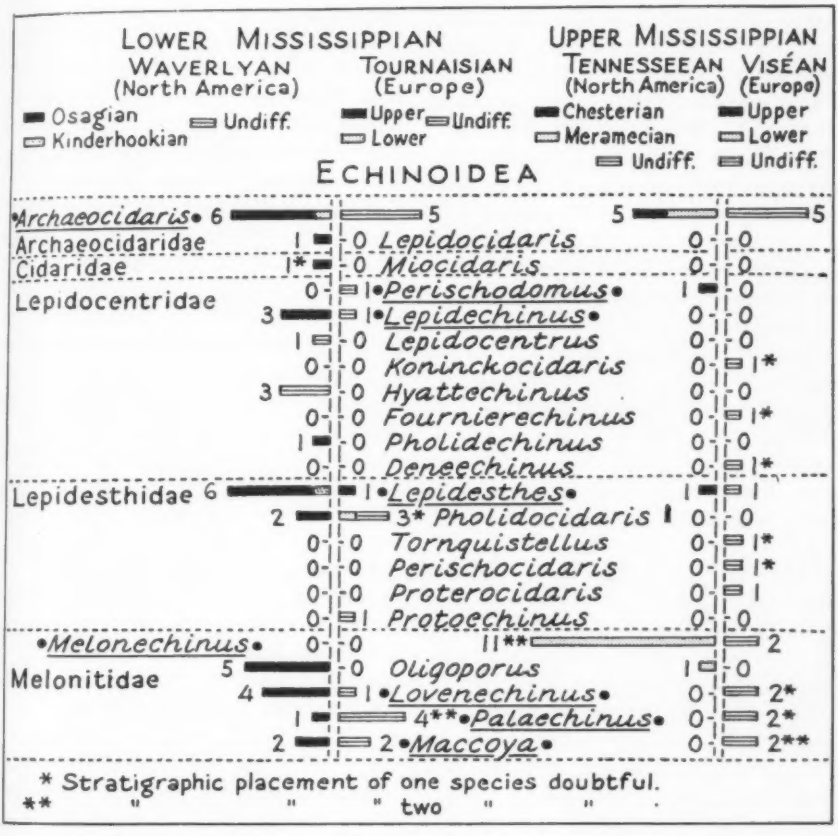

FIG. 13.—Comparison of Mississippian echinoids of North America and Europe. Genera common to both continents are underlined.

A noteworthy disparity in the distribution of bryozoans in rocks of Mississippian age on opposite sides of the Atlantic is the abundance of *Archimedes*, especially in Upper Osagian and Chesterian rocks of North America, as contrasted with the absence of this genus in Lower Carboniferous rocks of western Europe. Also, *Sulcoretepora*, which is represented by several American species, seemingly is not recorded from Lower Carboniferous rocks of Europe, possibly excepting *Sulcoretepora* (?) *raricosta* McCoy from Lower Carboniferous rocks of Ireland. Other American bryozoan genera of distinctive type, unknown in Europe, are *Lyropora* and *Evactinopora*.

BRACHIOPODS

The brachiopods are a group having considerable value for the comparative study of the paleontology of Mississippian rocks in North America and Europe; but, because of only slight distinctions between many species that are defined, a useful report on this group cannot be made without much more study than I have been able to undertake. One may point out that, in general, the same broad stocks, including productids, chonetids, schuchertellids, schizophorids, spiriferids, syringothyrids, and rhynchonellids, are present in both successions and that there is also a general similarity of sequence. Among the productids, subgenera such as *Productus* (ss), *Buxtonia*, *Avonia*, *Echinoconchus*, *Linoproductus*, *Pustula*, *Productella*, and *Dictyoclostus* are recognized in Europe and North America. Also, several species assigned to these genera in the respective continents are closely similar. As indicated in figure 1, the productids and other brachiopods have been used in zoning the British Mississippian rocks, and they are recognized to be useful also in differentiating horizons of the Lower and Upper Mississippian in many parts of North America. Representative types of European Lower Carboniferous brachiopods are illustrated in figure 14.

The chonetids of western Europe include some forms very closely similar to *Chonetes logani* and *C. glenparkensis*, which are characterized by broad plications bearing cross-wrinkles; it is interesting to find some of these representatives of typical Kinderhookian species in America, along with *Leptaena analoga* and others, represented in lower Tournaisian rocks of Belgium and England. On the other hand, chonetids of similar type have been reported from Viséan strata of western Germany (Paeckelmann, 1930).

Differentiation of several Mississippian species of *Schizophoria*, as recorded in American paleontological literature and according to the work of some Europeans, is of very doubtful validity, and there is now a tendency to refer these various examples of *Schizophoria* to a single species.

Rhynchonellid genera, such as *Tetracamera*, *Shumardella*, *Paryphorhynchus*, and *Pugnoides*, which are widely distributed in Mississippian rocks of North America, seem not to have been recognized in western Europe.

Summarizing these observations somewhat roughly, one may say that in Tournaisian rocks there are many more similarities to Lower Mississippian rocks of North America than appear in the Viséan, where the appearance of *Gigantella*, *Daviesella*, and some other forms finds no equivalent on this side of the Atlantic, except for sporadic occurrence of *Gigantella*, associated with *Striatifera* and Viséan types of corals, along the Pacific border of this continent (Merriam, 1942; Sutton, 1938, p. 552). The noteworthy contrast between brachiopod assemblages of the Tournaisian and the Viséan and younger Mississippian strata of western Europe is hardly matched by contrasts between Osagian and Meramecian rocks of North America.

PELECYPODS AND GASTROPODS

The *Posidonia* or P zone of the upper Viséan in the British Isles is designated in terms of a common thin-shelled clam, which occurs mostly in dark shaly deposits. It is similar in form to *Caneyella*, which is found in beds of presumably equivalent age in the Caney and Moorefield shales of the central United States. I have collected *Posidonia* in association with ammonites in the Moorefield shale near Batesville, Arkansas.

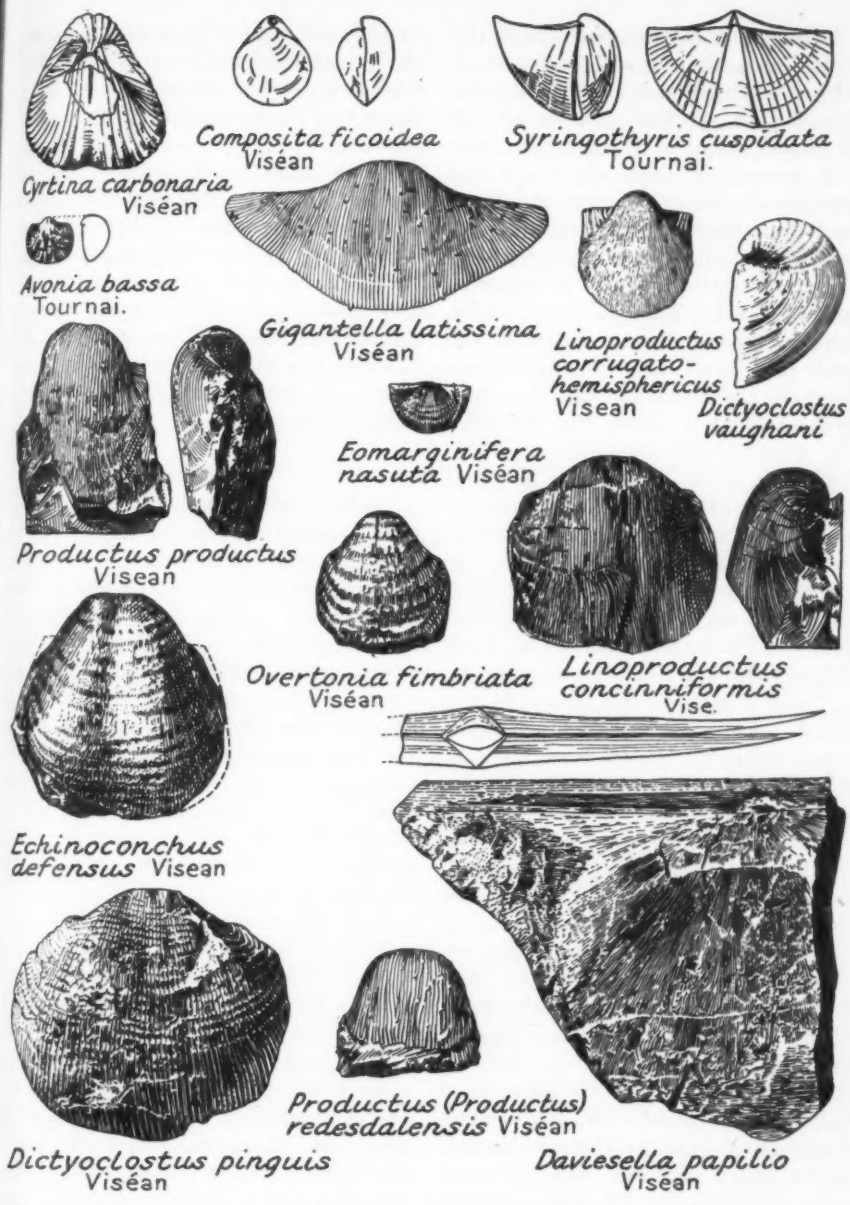

FIG. 14.—Representative brachiopods on Lower Carboniferous rocks of the British Isles and Germany

Another time-stratigraphic unit in the British area that is differentiated in terms of a pelecypod as guide fossil is the *Modiola lata* or Km subzone of the *Cleistopora* zone, of Etroeungtian age.

In general, neither pelecypods nor gastropods have yet been proved to have much importance for stratigraphic zonation or correlation of Mississippian deposits. Illustrative of this is extensive work by Hind (1896–1905) on a varied well-preserved molluscan fauna in the upper part of the Lower Carboniferous succession in Scotland; this was presumed to match closely the Nebraska City fauna described by Geinitz (1866) and Meek (1872), despite the fact that the Nebraska City fossils occur near the top of the Pennsylvanian succession in the northern Mid-Continent region.

Newell (1937) in studying the Pectinacea has noted the occurrence of two species of *Pterinopectinella* and one each of *Limipecten* and *Streblopteria* occurring in Lower Carboniferous strata of the British Isles; these shells are somewhat closely similar to forms known from the Mississippian of the United States. The genus *Obliquipecten*, which occurs in Viséan rocks of northern England, is not yet known outside the British area. Among myalinids (Newell, 1942) the genus *Myalina* ranges from Meramecian to Leonardian, *Septimyalina* from Chesterian and Viséan to Wolfcampian, and *Promytilus* from Viséan to Guadalupian. All three genera occur in Viséan rocks of England. A species of *Myalina* from the St. Louis limestone of the Mississippi Valley closely resembles *M. goldfussiana*, the genotype, from the Viséan of Europe. *Septimyalina angulata*, from Chester rocks of Illinois and Missouri, is rather closely similar to species assigned to this genus described by Hind (1896–1905) from England. Newell (1942, p. 52) has recognized a regular progression of morphologic features in the evolution of the mytilacean shells, indicating that these clams may have value in stratigraphic zonation.

Weller (1926) has defined the zone of *Sulcatopinna missouriensis* at the summit of Chesterian rocks in Illinois, and Laudon (1931) has differentiated Kinderhookian zones in terms of pelecypods and gastropods (*Palaeoneilo barrisi*, *Straparollus obtusus*, *Loxonema*) (fig. 2). According to present information, these zones are not known to have much value except locally.

CEPHALOPODS

Cephalopods, especially ammonoids, which exhibit a wide variety of shell form, surface ornamentation, and suture pattern, are presumed to be among the most useful fossils for stratigraphic zonation and for correlation, even between basins on different continents. Extensive work in western Europe has demonstrated the value of these fossils, both for definition of a widely recognizable succession of zones and also in some areas for rather fine subdivision of these zones. The work of Bisat (1928, 1936) in England and of Schmidt (1928) and Delépine (1928) on the Continent is especially noteworthy and has made invaluable contributions to stratigraphic differentiation of the Culm or Kohlenkalk facies of the Viséan deposits and classification of the Namurian beds.

Inasmuch as the ammonoids are the subject of a special paper contributed to this symposium by A. K. Miller, I shall treat the group somewhat cursorily. Significant data of stratigraphic distribution and inferred phylogenetic relationships, based mainly on studies by Bisat, are presented in figures 15 and 16. In these diagrams species that are repre-

sented by identical or very closely similar American forms are indicated by an asterisk. Characteristic types of Lower Carboniferous ammonoids are illustrated in figure 17.

Observations that seem to me to have chief importance are the following:

1. The occurrence in western Europe and the United States of identical or very closely similar forms of *Protocanites*, *Imitoceras*, and *Muensteroceras*, found, respectively, in Tournaisian and Waverlyan rocks, clearly indicates a general time correspondence of these divisions.

2. The zone of *Beyrichoceras* is very clearly established in western Europe, both in the British Isles and on the Continent, as middle Viséan in age (figs. 1,

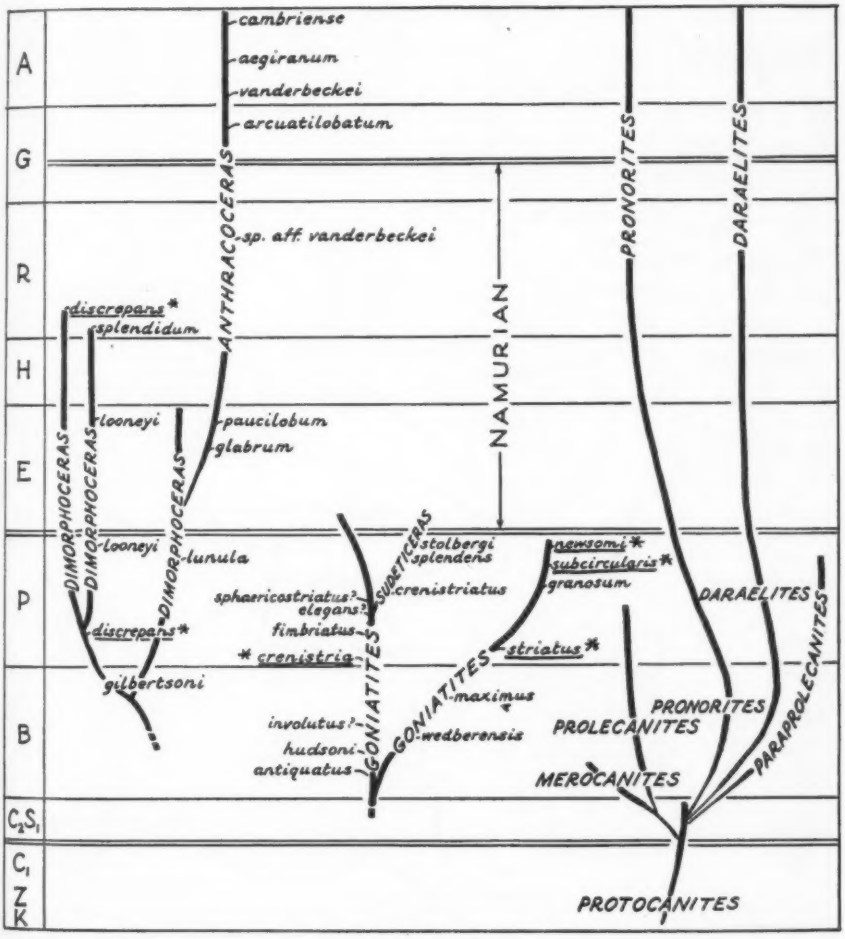

FIG. 15.—Viséan and Namurian ammonoid zones of the British Isles, showing distribution of species and inferred phylogeny of genera (data from Bisat).

15, 16). Beds belonging to this zone and containing its diagnostic fossils have been found to interfinger with strata of the coral-brachiopod zones in a manner to show that the B_1 subzone corresponds to the S_2 subzone containing numerous *Lithostrotion* and other characteristic Upper Mississippian corals, brachiopods, and other fossils (Hudson and Turner, 1933*a*); the B_2 subzone is found to correspond in age to the D_1 subzone, which very surely is not older than Meramecian deposits of North America and possibly belongs to the Lower Chesterian. Discovery of a representative of *Beyrichoceras* in the Osagian rocks of North America, as reported by Miller (1947), constitutes the record of a single identi-

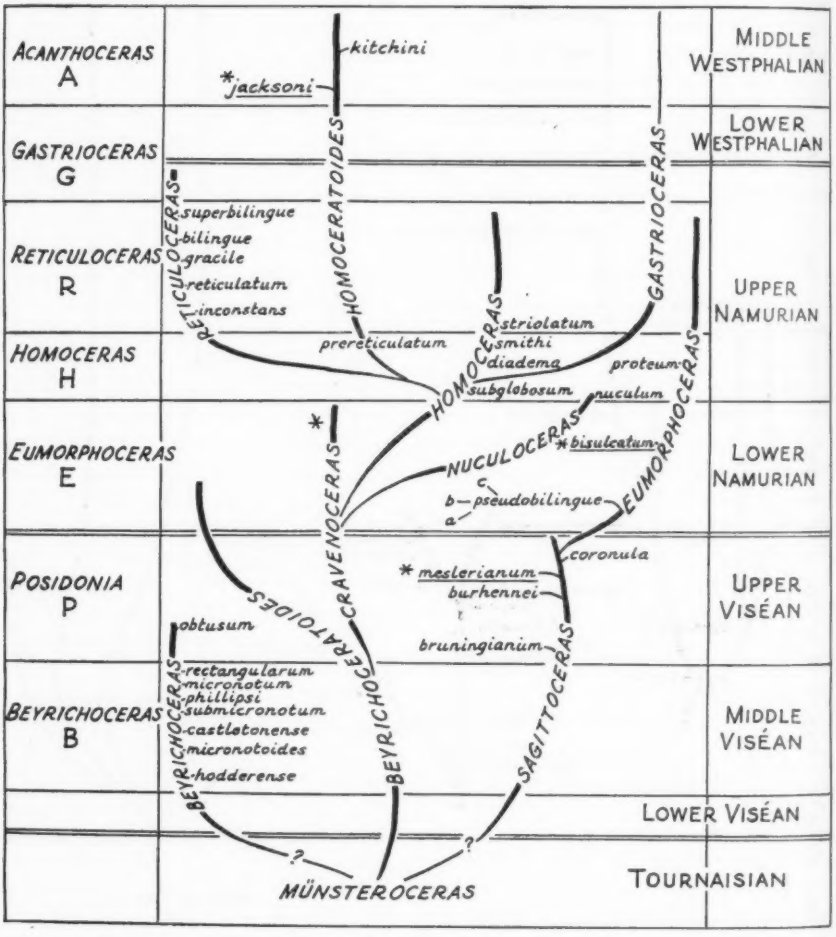

FIG. 16.—Viséan and Namurian ammonoid zones of the British Isles, showing distribution of species and inferred phylogeny of genera (data from Bisat).

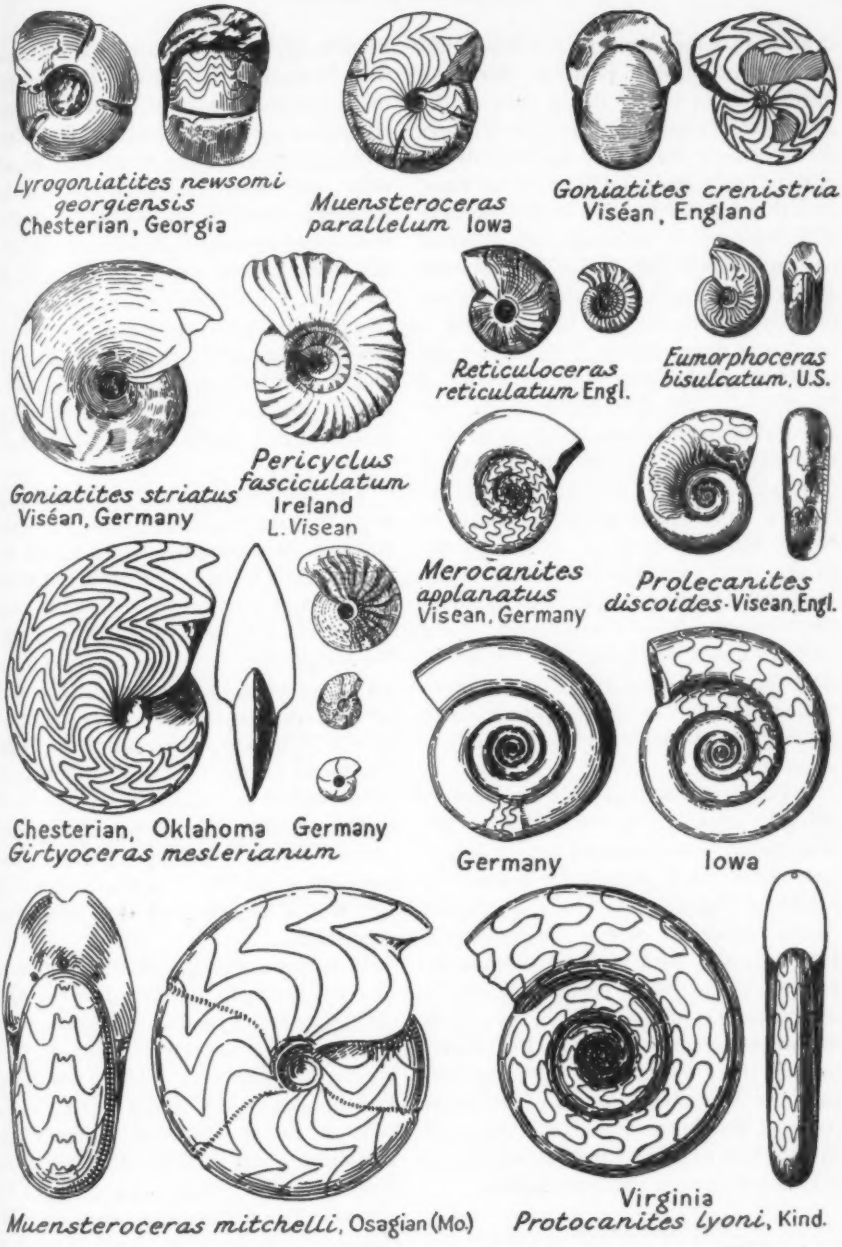

FIG. 17.—Representative Mississippian ammonoids from North America and western Europe (somewhat reduced).

fication of a representative of this genus in a stratigraphic position that can hardly fail to be far below that of the *Beyrichoceras* zone as defined in Europe. *Beyrichoceras* may have become differentiated as a genus in Tournaisian time, and the region in which it first became differentiated is unknown. As pointed out by Miller, the distinction between *Beyrichoceras* and *Muensteroceras* is extremely small, and the latter genus is very well developed in Tournaisian deposits. Overwhelming evidence supplied by crinoids, echinoids, brachiopods, corals, and probably other fossils, is utterly in conflict with the supposition that the European D zone can possibly be equivalent to pre-Meramecian deposits of North America. It is unfortunate that, as yet, numerous representatives of the European D zone have not been found on the western side of the Atlantic. Until such evidence is found, the record of *Beyrichoceras* in early Mississippian rocks of this continent cannot be permitted to outweigh abundant evidence of a differing sort.

3. Fossils of the *Posidonia* and *Eumorphoceras* zones in western Europe are distributed in well-defined successive arrangements that permit recognition of subzones. This seems not to be the case in North America, where characteristic P-zone fossils, such as *Goniatites crenistria*, are found in the selfsame layers as are diagnostic fossils of the E zone, such as *Eumorphoceras bisulcatum*. Rocks containing these fossils have been referred to upper Meramecian and to Chesterian parts of the Mississippian column, and the problem of their correct stratigraphic placement has not yet been solved.

CONCLUSION

The paleontological comparison, somewhat cursorily made in this study, indicates many points of correspondence and some notable dissimilarities between the distributions of fossils in rocks of Mississippian age on opposite sides of the Atlantic. In the light of present knowledge the most important fossils for paleontological zonation and correlation are judged to be the corals, brachiopods, blastoids, crinoids, echinoids, and ammonoids. With varying exactitude these fossils have been employed for widely applicable zonation in western Europe; and the beginnings of an equally useful, widely applicable zonation in Mississippian rocks of North America have been made.

The comparative study strongly suggests that the most important line of partition in Mississippian rocks is that between the Tournaisian and Viséan, which on this continent corresponds to the line between Osagian and Meramecian strata. No satisfactory basis has yet been found for recognizing the position of the Kinderhookian-Osagian boundary in terms of the European succession. Likewise, placement of the Meramecian-Chesterian boundary in western Europe is in doubt; probably this belongs in the lower part of the D zone approximately corresponding to the boundary between the B and P zones of the ammonoid succession.

It is unsatisfactory that doubt must be recorded as to placement of the Mississippian-Pennsylvanian boundary in terms of the western European Carboniferous deposits. The lowermost Westphalian rocks assigned to the G_1 subzone, as indicated both by marine invertebrates and by land plants, is Early Pennsylvanian (Morrowan) in age. No equivalents of the *Homoceras* and *Reticuloceras* zones have been found in North America. It is possible that not only the upper part of the D zone but the

entire Namurian is of Chesterian age. In most sections, however, there is no pronounced break either stratigraphically or faunally between the Namurian and the overlying lower Westphalian. Locally, as in central England, there is noteworthy unconformity between the Carboniferous limestone series, with D beds at the top, and the succeeding Millstone grit of Namurian age; and accompanying this break is a marked change in lithology. On the other hand, Millstone grit sedimentation begins in some areas below the top of the D zone.

Intercontinental correlations between North America and Europe in the Lower Carboniferous part of the column are by no means definitely established.

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